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INFORMATION TECHNOLOGY INVESTMENT AND NATIONAL PRODUCTIVITY GROWTH

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Abstract

Using the country-level information technology (IT) expenditures and productivity data for the period from 1992 to 2000, we estimate production function augmented with IT capital stock in the first-difference form. As discussed in prior studies, we confirm that IT expenditures have significant positive effects on national productivity growth. The effects of IT expenditure on productivity growth hold for a short-term (1-year) as well as for a longer-term (4-year and 8-year). Using two theory-based measures of IT maturity, we find that the IT maturity is an important factor that explains the relationship between IT expenditures and national productivity. In addition, we find that the effect of IT expenditures is even higher when the countries are at the mature stage of IT expenditures. Furthermore, we present evidence that IT externalities improve the effect of IT expenditures on productivity growth.

Keywords: Information technology investment, national productivity, knowledge spillover, growth, long-term effects

Introduction

After many years of debate on the *productivity paradox,*[1] several researchers have found a positive relationship between information technology and productivity (Brynjolfsson and Hitt 1996; Dewan and Min 1997; Hitt 1999; Menon et al. 2000; Miller and Doyle 1987; Mukhopadhyay et al. 1995; Tam 1998). These studies document significant positive returns of IT investment at both firm and industry level. Their results were corroborated by quite a few studies and initiated a large stream of research in this area. Although studies have proliferated, encouraging evidence of IT payoffs, there are limitations on the implications of results. In particular, noting that the IT productivity paradox was originally defined at the economy level, one natural concern is that most information systems studies have addressed the productivity question at the micro level (Chan 2000).

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[1]Brynjolfsson and Hitt (1998) note that there are three different periods in terms of IT maturity. They describe the period of 1985 to 1992 as the "productivity paradox period," when the methods for data collection and information technology value analysis were still under development. On the contrary, they refer the period of 1992 to 1995 as the "information payoff period," and the current period from 1996 to present as the "new organization period."

More recently, a few studies expanded the question to a country level. For example, Dewan and Kraemer (2000) examine data from a cross section of countries over time, and find that the contribution of IT capital investment toward the national output is not significant for the developing countries, but is significant and positive for the developed countries. In a similar vein, Gust and Marquez (2001) find that, due to the IT investment, labor productivity has accelerated significantly more in the United States than in other industrialized countries.

Our study shows that most of the sample countries have already experienced positive returns from IT investment. Figure 1 presents a scatter plot of the average annual growth rate of IT capital stock per worker and the average annual growth rate of output per worker for the period between 1992 and 2000. The sample includes a total of 43 countries, and the annual growth rates of IT capital stock ranges between –0.8 percent and 22.6 percent. The sample countries are clustered into four groups in terms of IT capital stock per labor and the four groups are separately noted. Interestingly, although the elasticity of the IT stock growth is different among groups, most countries began to experience positive returns from IT expenditures.

With the accumulation of such positive evidence of IT investment, natural questions are why countries experience a different elasticity of IT investment, and what amplifies the contribution of IT investment to national productivity. This paper extends the question of the productivity effects of IT investment, and investigates how the IT investment improves the national productivity growth based on estimation of production function augmented by IT capital stock. Using a pooled time-series data set of 43 countries from 1992 to 2000, we first examine the relation between national productivity growth and IT stock growth of each country where IT capital stocks were estimated based on IT investment series for each country. Despite insufficient empirical evidence, the previous studies have assumed that matured IT stocks are needed to realize the positive contribution of IT expenditures on the productivity growth. This study empirically investigates the impacts of IT maturity on the growth of national productivity. Employing the country-level analysis conducted by Dewan and Kraemer, we find that IT maturity is a factor influencing the contribution of IT capital to the productivity.

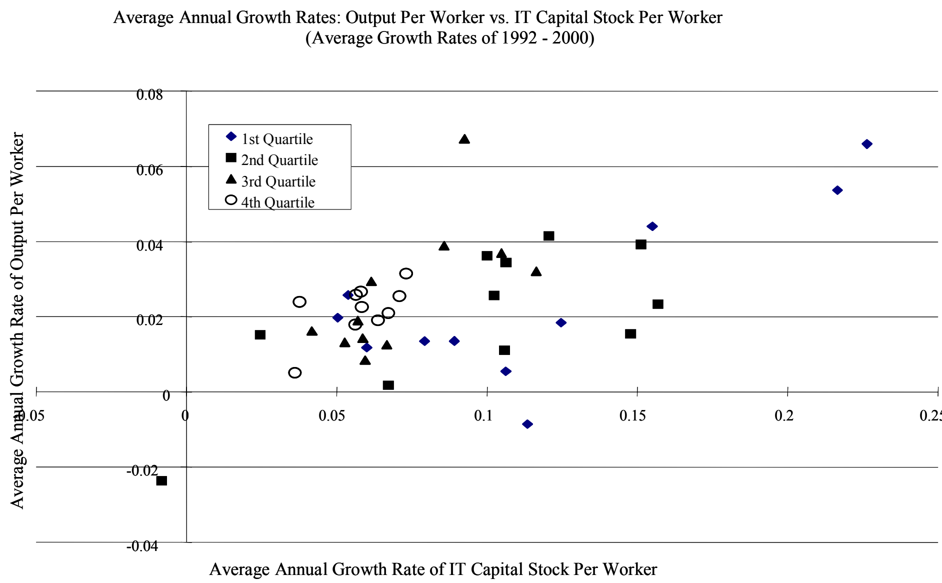

Figure 1. Growth of IT Expenditures and Growth of Productivity

It is important to note that we employ sample clustering methods that were not used by earlier studies. Dewan and Kraemer divide 36 countries into "developed countries" and "developing countries" based on the 1990 GDP per worker, and find that countries in the high GDP per worker tend to have higher levels of IT investment as a percentage of GDP. They argue that other infrastructure such as human capital, informatization of business process, and existing capital stock are important factors making IT investment productive. In this study, we propose that IT maturity is one of the indicators discriminating the IT contribution on the productivity. Relying on innovation literature, we consider level of IT capital stock per worker as a meaningful indicator of IT maturity. Groups of countries are formed depending on the level of IT capital stock per worker and the respective elasticities of productivity growth to IT investment are estimated.

In an alternative specification of the production function, we investigate the nature of dynamic technology externalities and their implications for national productivity. We identify that the level of IT capital stock per labor creates positive externality in addition to serving as a productive input in the production function. We interpret this externality effect as another form of representation of IT maturity effect. The empirical method in this study uses first-difference approach, which releases us from the common issue of non-stationarity (Pedroni 1999) in the time-series data. Our main findings are robust against several choices of growth periods and alternative model specifications.

The rest of the paper is organized as follows. The next section provides the theoretical background for research. The specific forms of production functions with consideration of IT capital stock are then presented. Our data set and variables of the basic growth regression are described. Our empirical findings are presented and their robustness to various measurement period of national productivity growth checked. Finally, the paper concludes with a summary and implication

Theoretical Background

Despite information technologies being attractive, they bear the inherent the risk of technology innovation. The dilemma of innovation with information technologies is well discussed in Schumpeter's view of capitalist development. Schumpeter (1935) and Rosenberg (1982) view the capitalist development as an equilibrium cycle involving producers and suppliers in which technology innovation was a *destabilizing factor*, resulting in unexpected changes to both parties. While the process of technology innovation is neither smooth nor predictable, and its uncertainty is a grave source of risk, technology maturity has been viewed as a factor that decreases uncertainty of IT investment.

Factors dividing such evolutionary process of technology adoption have been well discussed in the literature . Dewan and Kraemer (2000) suggest that a country's GDP level is associated with the maturity level of national IT innovation. Using the sample countries grouped by developed countries and developing countries based on the 1990 GDP per worker, they find that countries in the high GDP per worker cluster tend to have higher levels of IT investment as a percentage of GDP, and that developed countries have already accumulated matured IT stocks. We investigate the impact of IT maturity based on two alternative measures incorporated in production function: IT expenditure-based maturity and IT externalities.

IT Expenditure-Based Maturity

In order to explain the technology dissemination, the imitation lag theory posits that there is a learning period during which a country must acquire technology and know-how in order to increase production. In addition, it takes time to adopt, implement, and utilize technologies to bring the finished products to the market (Appleyard and Field 1998). Furthermore, most information technologies must be customized to meet the needs of individual users and constantly enhanced to retain users, especially in the IT sector, which includes computers and telecommunication equipment as capital goods of service industries (Shapiro and Varian 1999). Such technology innovations are important irrespective of productivity because, although a country does not have the means of producing IT innovations, it can still profit from the effective application of innovations in other sectors (King et al. 1994).

Dewan and Kraemer argue that there are learning periods for each country so that countries must obtain a certain level of experience with information technologies before investments in this relatively new factor of production start to pay off. They conclude that the developed countries have learned how to use the technology effectively over the past 30 years, and part of the cost of their IT investments can usefully be viewed as the tuition paid for that learning. In a similar vein, Gust and Marquez (2001) find that, due to the IT investment, labor productivity has accelerated significantly more in the United States than in other industrialized countries. They use the annual growth rate of labor productivity from the Bureau of Labor Statistics (BLS) as an estimate of labor productivity growth, and use the ratio of investment in IT equipment to nonresidential gross fixed capital formation as a measure of IT investment. They find that the ratio of IT capital to total capital has increased more in the United States than other G-7 countries. Shapiro and Varian (1999) argue that IT value does not simply mean implementation of hardware or software, but IT usage that requires a certain amount of time for users to train themselves until they find IT useful. As such, IT investment generally requires a learning period for users before it generates output. Furthermore, David (1990) argues that IT may require substantial changes in complementary infrastructure (e.g., human and knowledge capital, global communications infrastructure, etc.) before the gains are realized. In general, creating an IT knowledge base requires more time than IT implementation, and IT-matured countries benefit more from information technology because of the IT knowledge base.

IT maturity has been discussed with IT intensity. Harris and Katz (1991) defined *IT intensity* as the ratio of annual IS expenses to total expenses or sales. Dewan and Min (1997) separate firms into two subgroups based on IT intensity, measured by the factor share of IT capital among the inputs to production. They find IT capital stock as a more meaningful indicator of the production technology than annual IS expenses. The results of the study support that an average firm in the low IT intensity group is less capital intensive but more labor intensive than its counterpart in the high IT intensity group.

IT has been viewed as one of the most important innovations of the last three decades. As such, the growth pattern of IT over time may be analyzed from the perspective of the diffusion of innovation literature. Based on the studies in this area, Gurbaxani and Mendelson (1990) identify two patterns of growth in different periods of IT growth: an early transient period, when people in a country gain familiarity with IT, and a steady growth period, when IT expenditures continue to grow steadily as a result of the positive returns of IT itself. As the IT and user become mature, the transient behavior in period converges to the steady-state IS spending behavior. In essence, IT-matured countries increase their IT expenditure because they have already realized the benefit from IT. As such, IT expenditure operates as a good indicator of IT maturity. It also implies that the more innovative a group is, the more they spend on information technology. Furthermore, innovative countries are at a relatively more technologically matured stage than less innovative countries, since the former began to adopt technologies earlier than the latter.

We investigate the relation between country's IT maturity level and the effect of IT investment on productivity growth. To measure the relationship between IT maturity and productivity, we first classify sample countries into four quartile groups based on the level of IT capital stock per labor. The production function is estimated taking into consideration of the differential productivity impact of IT stock depending on the IT maturity level of a country. This approach not only differentiates the current study from the previous studies, it also provides a new implication of IT investment based on innovation theory. The proposition generates a set of hypotheses that are tested using aggregate IT expenditure data collected by World Bank. Our empirical investigation provides evidence supporting the hypotheses of the previous studies in the area of IS spending.

IT Externalities

IS researchers have increasingly begun to understand the contribution of IT investment as a product of individual efforts taking place in a network context where the infrastructure and communication technology, together with changing externalities in the uses of IT, affect the historical paths taken in shaping the growth of IT contributions (Shapiro and Varian 1999). David (1988) describes the contribution of information technology based on explicit network phenomenon, and argues that the externalities based on this technology knowledge network are generally proportional to maturity of stock that requires time to compile.

Investment in knowledge creation such as research and information technology suggests a natural externality. The creation of new IT knowledge by one firm is assumed to have a positive external effect on the production possibilities of other parties because it is possible to create a large pool of IT knowledge when the technologies are being used by many parties. Most importantly, production of consumption goods as a function of the stock of IT knowledge and other inputs exhibits increasing returns; more precisely, IT knowledge may have an increasing marginal product. In contrast to models in which capital exhibits diminishing marginal productivity, IT knowledge will grow without bound.

In explanation of the phenomenal growth of IT investments and its impact on productivity, the dynamic view of technology and knowledge concentration with the recent work on economic growth views technology externalities as the driving force for technological innovation. The theory explains that the value of IT depends on its knowledge externalities because the contribution of IT arises not simply from implementation of computer hardware or software, but from IT usage that requires user learning and knowledge sharing. As far as knowledge concerns, researchers agree that the IT payoffs not only result from implementation of hardware and software, but from the IT knowledge base as well. With terminology used in Glaeser et al. (1992), dynamic externalities deal with the role of prior domestic information accumulations on current productivity. Such internal accumulations are accomplished by a history of interactions with information technologies and cultivated long-term experience, which lead to a buildup of knowledge available to domestic production units. Since these technology externalities arise from both intended and unintended communications among economic agents over time, their effects should be more readily observed in places in which communications and technologies are focused. Empirical evidence suggests that important knowledge spillover might occur within a country. As such, concentration of technologies within a county can facilitate spillovers of knowledge and innovations, increasing the national productivity.

Recent developments of endogenous growth models have stressed the role of knowledge spillovers in generating growth (Lucas 1988; Romer 1986). Romer (1990) argues that long-run growth is driven primarily by the accumulation of knowledge by forwardlooking, profit-maximizing agents. This focus on knowledge as the basic form of capital suggests natural changes in the formulation of the standard aggregate growth model. In an alternative specification of production function, our study takes the basic framework of endogenous growth model and considers IT capital stock per labor as the main force influencing the knowledge base and thus generating positive externality. According to David (1988), this formulation may be interpreted as an alternative form of evidence of maturity effect.

Production Function Estimation Approach

This study investigates the productivity effect of IT investments based on estimation of production function augmented with IT capital stock. In our base model, IT capital stock is explicitly included as a factor of input in addition to the traditional factors, physical capital and labor. A three-factor production function with Cobb-Douglas technology under constant returns to scale is shown as follows.

$$Y(t) = A\exp(ct)K\ (t)^{\beta_K} K_{IT}(t)^{\beta_{IT}} L(t)^{1-\beta_K-\beta_{IT}},\ 0 < \beta_K, \beta_{IT} < 1,\ \beta_K + \beta_{IT} < 1 \qquad (3.1)$$

where Y(t) is the output, K(t) is the non-IT related physical capital stock, K_{IT}(t) is the IT capital stock, and L(t) is the labor at period t. A represents the technological level and c is the constant rate of technological advance in the production technology. Dividing each side by L(t) and expressing the production function in terms of output per labor, we obtain production function in intensity form.

$$y(t) = A\exp(ct)k(t)^{\beta_K} k_{IT}(t)^{\beta_{IT}} \qquad (3.2)$$

where $y(t)$ (= $Y(t)/L(t)$) is output per labor, $k(t)$ (= $K(t)/L(t)$) is non-IT physical capital stock per labor, and $k_{IT}(t)$ (= $K_{IT}(t)/L(t)$) is IT capital stock per labor. Taking logs of both sides, we obtain the following.

$$\log y(t) = \log A + c \cdot t + \beta_K \log k(t) + \beta_{IT} \log k_{IT}(t) \qquad (3.3)$$

As the dependant and independent variables are time-series variables exhibiting non-stationarity the error term is subject to a unit-root problem under which the standard errors of the OLS estimates are biased. The estimation in levels as shown in equation (3.3) may lead to spurious results where the common inference based on the standard errors of OLS estimates will not be valid. To avoid the non-stationarity problem in our analysis, we use first-difference approach by taking the first-difference of equation (3.3) as follows.[2]

$$d\log y(t) = c + \beta_K d\log k(t) + \beta_{IT} d\log k_{IT}(t) \qquad (3.4)$$

where $d\log y(t)$ is $\log y(t) - \log y(t-1)$, $d\log k(t)$ is $\log k(t) - \log k(t-1)$, and $d\log k_{IT}(t)$ is $\log k_{IT}(t) - \log k_{IT}(t-1)$. Since the 1-year first-difference approach has the disadvantage of capturing only the short-run variations in the observations, we consider regressions based on the non-overlapping differenced series of alternative lengths: 1-year, 4-year, and 8-year growth rates. Each differenced series creates a respective panel data set.[3]

The main focus of our study is the maturity effect of IT stocks. As discussed in the previous sections, one measure that may proxy the maturity of an IT investment in a country is the amount of accumulated spending on IT. To control for the size of an economy, we use the level of IT stock per worker (K_{IT}/L) as a maturity measure and categorize our sample countries based on quartiles of K_{IT}/L, with a fourth-quartile country having the highest maturity. In order to investigate whether IT capital has differential impacts on the labor productivity depending on the country's IT maturity, we additionally introduce variables of IT capital stock interacted with IT maturity quartile group dummies as shown in the following model.

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[2]An alternative would be to consider level regressions based on the panel co-integration method. Panel co-integration tests were recently developed by Pedroni (1999).

[3]A data set based on 8-year interval series is reduced to cross-section data as it allows only a single observation for each country.

$$d \log y(t) = c + \beta_K \cdot d \log k(t) + \beta_{IT} \cdot d \log k_{IT}(t)$$

$$+ \beta_{IT,2} d \log k_{IT,q2}(t) + \beta_{IT,3} d \log k_{IT,q3}(t) + \beta_{IT,4} d \log k_{IT,q4}(t) \quad (3.5)$$

where $logk_{IT,qi}=logk_{IT}*dum_{qi}$ and dum_{qi} is the group dummy variable for countries in quartile i (i = 2, 3, 4).

As discussed in the previous section, maturity effect of IT investment can be alternatively shown by the presence of externality effect. Models of endogenous growth provide a theoretical framework where knowledge spillovers raise productivity growth (Grossman and Helpman 1991; Romer 1990). The central idea of the theory is that the productivity growth dynamics are governed by the externalities generated by the accumulation of intangibles such as human capital, research and development stock, or IT stocks. However, as scale effects implied by endognenous growth models are not consistent with the empirical evidence, we follow the work of Jones (1995) and of Dinopoulos and Thompson (2000) who develop versions of Romer models without scale effects. Our study considers IT capital stock per labor as the driving force influencing the productivity growth. The productivity growth effect of IT capital per labor is introduced in the following equation representing productivity growth dynamics.

$$\dot{A} / A = \beta_{ext} \cdot \log k_{IT}(t) \quad (3.6)$$

where $\dot{A} = dA / dt$. Incorporating equation (3.6) into equation (3.4), we obtain

$$d \log y(t) = c + \beta_K d \log k(t) + \beta_{IT} d \log k_{IT}(t) + \beta_{ext} \log k_{IT}(t) \quad (3.7)$$

Significance of β_{IT} will suggest importance of the IT stock as a factor of input while significance of β_{ext} will suggest the presence of externality effect from IT investment which in turn provides evidence of the maturity effect of IT proposed in this study.

Data and Variables

Real GDP, number of workers, and real investments are obtained from the latest data set of Penn World Tables (PWT 6.1), which is updated to year 2000. Since capital stock series are not available in the new version of PWT 6.1, aggregate capital stocks were estimated from the real investment series for each country. Since the initial aggregate capital stocks were not available, they were estimated using the following formula:

$$K_{i0} = Inv_{i0} / (\gamma_i + g_i) \quad (4.1)$$

where Inv_{i0} is the initial investment for country i. The investment growth rates (g_i) were calculated using the earliest 10years of investment data available and the retirement rates (γ_i) are assumed to be 5 percent. Given the estimated initial aggregate capital stock, the investments are then accumulated to form the subsequent aggregate stock series based on the perpetual inventory method.

The shares of information and communication technology expenditures[4] in GDP were obtained from the World Bank database (2002) for 43 countries for the period from 1992 to 2000. The shares were multiplied to the real GDP of the PWT to estimate the real IT expenditures. Based on the derived IT expenditure series, we estimate the IT stock using the same method described above in constructing aggregate physical capital stocks, however with an assumed depreciation rate of 10 percent to reflect the shorter

[4]Information and communications technology expenditures include external and internal spending on information technology, and spending on telecommunications and other office equipment. External spending includes tangible spending on information technology products purchased by businesses, households, governments, and education institutions from vendors or organizations outside the purchasing entity, while internal spending includes intangible spending on internally customized software, capital depreciation, and the like.

service life of IT expenditure.[5] Non-IT physical capital stock (*K*) in equation (3.1) is derived by taking the difference of the aggregate physical capital stock and the estimated IT capital stock.

Empirical Implementation and Results

In this section, we perform statistical analysis of the hypothesis that the maturity of IT stocks and IT externalities are positively related to the national productivity growth. All hypotheses are tested in three period estimations: 1-year, 4-year, and 8-year growth estimations. 1-year growth estimation uses the growth ratio of IT stock and productivity between two consecutive years, while 8-year growth estimation investigates the growth effects over a nine-year period. These estimation schemes not only provide robustness of the results, but also allow us to observe short-term and long-term productivity effects. We first report descriptive statistics of the key variables. We then describe the results of the regression analysis.

Summary Statistics

Table 1 presents the sample characteristics of 43 countries included in the sample.[6] First, the level of IT capital stock per worker was obtained, and each country's average ratio of the IT capital stock per worker for the nine years (1992~2000) was calculated. All sample countries are ordered by the average ratio, and clustered into quartile groups.[7] According to the innovation theory, technologically matured groups generally invest more in technologies. We believe that this clustering method allows us to group countries based on each country's IT maturity.

Table 1. Average IT Capital Stock Per Worker by Quartile Group (1992~2000)

Quartile Group by IT Maturity	# of Countries	Mean	Std.	Minimum	Maximum
Q1	11	1508.57	910.13	3198.86	446.44
Q2	11	5348.66	1024.28	7470.19	3789.03
Q3	11	13902.96	2829.60	17718.88	8761.61
Q4	10	20970.98	3485.19	29392.95	18007.79
All Countries	43	10187.72	7881.51	29392.95	446.44

Note: The units are 1996 constant U.S. dollars.

The mean of each group is calculated and compared by one-way ANOVA analysis. The results of the analysis show that the four groups are significantly different in terms of their IT expenditures ($p < 0.001$). The means of the least-matured (first quartile group) and most-matured (fourth quartile group) country groups are $1,508.57 and $20,970.98 respectively during the observation period from 1992 to 2000, while the mean of the 43 sample countries is $10,187.72. The main characteristics of four variables are presented in Table 2. GDP per worker, and non-IT/IT capital per worker are growth ratio in percent. Definitions of each data were discussed in earlier in this paper.

[5]Our main results are also robust to 15 percent depreciation rate assumption in estimating IT capital stocks.

[6]World Bank Database provides 50 countries' IT expenditure in the period 1992-2000. Because of missing data, only 43 countries are included in Table 1.

[7]The first quartile group (Q1) includes India, China, Romania, Philippines, Indonesia, Egypt, Poland, Turkey, Thailand, Colombia, and Brazil. The second quartile group (Q2) consists of Argentina, Slovenia, Slovak Republic, Greece, Hungary, Chile, Mexico, Portugal, Malaysia, Venezuela, and South Africa. The third quartile group (Q3) contains South Korea, Spain, Finland, Italy, Ireland, Japan, Hong Kong, Austria, Germany, Norway, and France. Finally, the fourth quartile group (Q4) includes Denmark, Belgium, New Zealand, United Kingdom, Netherlands, Canada, Sweden, Australia, Switzerland, and United States. All countries are ordered by the ratio of IT stocks over labor.

Table 2. Summary Figures (Production Function Input (1992~2000); N = 45)

Variables	Mean	Standard Deviation	Minimum	Maximum
GDP per Worker (*dlog y(t)*)	0.023	0.017	-0.024	0.067
Non-IT Capital per Worker (*dlog k(t)*)	0.018	0.029	-0.049	0.083
IT Capital per Worker ($dlog\ k_{IT}(t)$)	0.087	0.047	-0.008	0.226
IT Externalities ($log\ k_{IT}(t)$)	0.010	0.008	0.000	0.029

Basic Model

OLS estimations are performed on the empirical models of the previous section against the pooled time-series data set of 43 countries for 1992~2000. The errors are assumed to be i.i.d. with normal distribution. The standard errors for the estimates are White-heteroscedastic consistent. Table 3 presents the regression results of the base model (equation 3.4). In order to capture the longer term effect of the IT expenditures on the productivity growth, the analysis of 1-year growth rate regression was repeated for non-overlapping 4-year average growth rates and for non-overlapping 8-year average growth rates based on respective observation points.[8] There are 346 country-level observations in 1-year growth estimation, 87 observations in 4-year growth estimation, and 43 observations in 8-year growth estimations without overlapping periods. The year dummies were initially included for 1-year and 4-year growth estimation. The dummies are significant in three periods of 1-year estimations, but not statistically significant in 4-year estimation. Consequently, year dummies are included in 1-year estimation, but excluded from 4-year estimation.[9] The coefficients of IT stock over labor, β_{IT}, in Table 3 are positive and statistically significant in all three regressions. The results of all three regression analyses show that the growth rate of IT stocks are significantly related to the growth of productivity.

Table 3. Production Function Estimates with Growth Model

	1-Year Growth	4-Year Growth	8-Year Growth
β_K	0.275*** (4.864)	0.325*** (4.892)	0.225*** (3.636)
β_{IT}	0.158*** (5.456)	0.188*** (3.886)	0.194*** (4.182)
R^2	0.202	0.379	0.479
N	346	87	43

Note: *p < .05, ** p < .01, *** p < .001

The year dummies are significant in 1-year estimation of three periods (1993~1994, 1998~1999, and 1999~2000). Corresponding untabulated results are $\beta_{93\text{-}94} = -0.019$ ($p < 0.01$), $\beta_{98\text{-}98} = -0.018$ ($p < 0.01$), and $\beta_{99\text{-}00} = -0.014$ ($p < 0.01$).

In a longitudinal study, the effects of IT expenditures on performance may be realized after a period of time. Brynjolfsson and Hitt (1998) suggest that more benefits would be observed over a longer time period. Devaraj and Kohli (2000) also argue that the maturity of the IT infrastructure can affect the duration necessary for IT to offer benefits. The results of analysis confirm that the coefficients and significance levels are sensitive to time period. The third row in the Table 3 corresponds to an elasticity of IT stock growth to output elasticity with respect to IT stock. The results suggest that growth of IT stock is significantly related to the growth rate of productivity in all three tests. Increasing elasticity of IT stock growth rate (β_{IT}), further suggests that the effect

[8]While 1-year difference equations may have the problem of capturing only the short frequency variations as well as being dominated more by other omitted variables not considered in our study, using longer average growth rate lessens the issue. We used 4-year and 8-year average growth rate regressions due to the data limitations as World Bank Database only has observations of IT expenditure from 1992 to 2000. Therefore, 8-year average growth rate regression is based on a cross-section data set. The 4-year and 8-year data structure allows us to avoid overlaps in the observation points, which is important as overlaps will complicate the treatment of the error terms.

[9]Results with and without year dummies for all specification did not alter our main findings. The results will be provided on request.

of IT stock growth on the productivity growth may be better captured in the longer time horizon ($\beta_{IT,1yr}$ = 0.157, $\beta_{IT,4yr}$ = 0.188, $\beta_{IT,8yr}$ = 0.194). The estimated R^2 indicates that the two variables, the growth of IT and non-IT capital stocks together explains 20.2 percent, 37.9 percent, and 47.9 percent in the growth of productivity in the three regressions respectively.

IT Maturity Effect

To estimate the IT maturity effects, the base model is tested with four groups where countries are clustered as discussed in the previous section. Table 4 provides OLS estimates of equation (3.5) where IT maturity quartile groups are introduced to the base model. The first quartile is the least-mature countries in IT expenditures and the fourth quartile is the most-mature countries in IT expenditures. The coefficients of the least-mature countries' IT expenditures, β_{IT}, in Table 4 are positive and statistically significant in all three regressions. The coefficient $\beta_{IT,\,q}$ (q = Q2, Q3, or Q4) measures additional growth effect of IT investment for each country in the respective quartile. For example, the coefficient $\beta_{IT,\,Q2}$ and $\beta_{IT/Q3}$ in Table 4 shows the IT stock growth effects over the productivity growth in addition to β_{IT} for the countries in the second and third quartile, respectively.

Table 4. Maturity Effects

	(I)	(II)	(III)	(IV)	(V)
	1-Year Growth	4-Year Growth	4-Year Growth	4-Year Growth	8-Year Growth
Sample Periods	**(1992-2000)**	**(1992-2000)**	**(1992-1996)**	**(1996-2000)**	**(1992-2000)**
β_K	0.267*** (4.771)	0.316*** (4.624)	0.295*** (3.194)	0.260* (2.309)	0.212*** (3.976)
β_{IT}	0.192*** (5.934)	0.237*** (4.752)	0.287*** (4.847)	0.198* (2.212)	0.246*** (5.222)
$\beta_{IT\ Q2}$	-0.035 (-0.946)	-0.024 (-0.482)	-0.127⁺ (-1.938)	0.112⁺ (1.884)	-0.010 (-0.248)
$\beta_{IT,\,Q3}$	0.106⁺ (1.710)	0.132⁺ (1.881)	0.025 (0.347)	0.285⁺ (1.952)	0.152⁺ (1.828)
$\beta_{IT,\,Q4}$	0.129* (2.181)	0.207** (2.681)	0.001 (0.012)	0.430*** (3.437)	0.222*** (3.668)
R^2	0.218	0.428	0.595	0.332	0.587
N	346	87	43	44	43

Note: ⁺p < .10, *p < .05, ** p < .01, *** p < .001.

Dependent variable is the growth rate of GDP per worker. The year dummies are significant in 1-year estimation of three periods (1993~1994, 1998~1999, and 1999~2000). Corresponding untabulated results are $\beta_{92\text{-}93}$ = –0.019 ($p <$ 0.01), $\beta_{97\text{-}98}$ = –0.017 ($p < 0.05$), and $\beta_{98\text{-}99}$ = –0.014 ($p < 0.05$).

The parameter estimates show that countries in all groups have experienced the positive return of IT expenditure during the sample period. The elasticity of IT stock growth on productivity growth is not significantly different between the first and second quartile groups as the estimates of $\beta_{IT,Q2}$ are not statistically different from zero as shown in column (I) of Table 4. However, the results show that the estimates of $\beta_{IT,\,Q3}$ and $\beta_{IT,\,Q4}$ are strongly positive and statistically different from zero. This implies that elasticity of IT stock is higher in the countries in the third and fourth quartiles. The countries that have developed relatively more matured IT stocks reap more benefits from IT stocks. The findings are robust and more pronounced for longer horizon regressions as shown in column (II) for 4-year growth regression and in column (V) for 8-year growth regression.

To determine whether the maturity effects have changed over time in our sample, 4-year growth regressions were separately performed on two subsamples: 1992-1996 and 1996-2000. In all subsample regressions as shown in columns (III) and (IV), the coefficient of IT capital stock (β_{IT}) is shown to be strongly significant. It is, however, interesting to note that the maturity effects were not statistically significant in the first subsample period (1992-1996) as in column (III) while it became significant in the second subsample period (1996-2000) as in column (IV).

Externalities Effects

As discussed in the earlier section on the production function estimation approach, the IT productivity model can be extended with externalities. Glaeser et al. (1992) argue that concentration represents the potential for externalities, and Henderson et al. (1995) show the reliability of the measure. We introduce the ratio of accumulated IT stocks to total labor in a country to represent the externality generated by aggregate IT investments of an economy. As explained in the earlier section, IT capital stock enters the production in two ways. As shown in an alternative specification of production function in equation (3.7), β_{IT} accounts for the effect of IT capital stock as a traditional productive input and β_{ext} accounts for the effect of IT externality or the effect of pure technology concentration which is proxied by the ratio of IT stocks over labor (ITK/L).

Table 5 presents the results of estimation of the production function with IT externalities based on equation (3.7). The average ratio of IT stock over labor for each time horizon is used in the respective regression. The results show that externalities have a significant effect on productivity in all three estimations based on the full sample as shown in columns (I), (II), and (V). Note that the elasticity of externalities is greater in 4-year and 8-year observations than 1-year estimation. The result suggests that the IT externalities, which are mostly based on IT knowledge accumulation and history of experience, pay off well in the long-term.

In an effort to illustrate the post-1996 effect as in the previous sub-section, two sets of 4-year estimations are executed with the first and second 4-year subsample periods. Comparing the columns (III) and (IV), we find interesting evidence that only β_{ext} in the second term appears to be statistically significant ($\beta_{ext} = 1.290$, $p < 0.01$). The resulting implication is consistent with the quartile group tests as shown in columns (III) and (IV) of Table 4. In the period 1992-1996, the influence of IT investment on productivity growth is captured only through its role as a basic input and the magnitude of influence is the same for all countries ($\beta_{IT} = 0.231$, $p < 0.01$). However, in the following period 1996-2000, the IT externality effect becomes significant. Countries experience additional benefits arising from externality corresponding to the level of IT capital stock per labor ($p < 0.01$) in addition to the returns from IT stock growth ($\beta_{IT/L} = 0.252$, $p < 0.01$). The result implies that the countries with higher levels of IT stock per labor will enjoy higher returns from IT investment, which is consistent with the results of the previous sub-section. Both the quartile-based maturity model and the externality-based maturity model, therefore, confirm that all countries had similar returns from IT before 1996, but have additional returns due to the matured IT knowledge base since.

The R^2 values indicate that, in addition to the variables of the basic model, externalities offer additional explanation. Together, the model explains 21.1 percent, 42.5 percent, and 56.4 percent of the variance of endogenous variable respectively in 1-year, 4-year, and 8-year growth estimation. Recall that the R^2 values are somewhat similar to the R^2 of quartile-based maturity estimation.

Table 5. The Externalities Effects

	1-Year Growth (I)	**4-Year Growth (II)**	**4-Year Growth (III)**	**4-Year Growth (IV)**	**8-Year Growth (V)**
Sample Periods	**(1992-2000)**	**(1992-2000)**	**(1992-1996)**	**(1996-2000)**	**(1992-2000)**
β_K	0.275*** (4.900)	0.327*** (4.701)	0.310*** (4.229)	0.300** (2.756)	0.229*** (4.128)
β_{IT}	0.193*** (5.527)	0.251*** (4.523)	0.231** (3.145)	0.252** (2.868)	0.259*** (5.260)
β_{ext}	0.497* (2.298)	0.767** (2.704)	0.081 (0.226)	1.290** (3.140)	0.762*** (3.165)
R^2	0.211	0.425	0.531	0.359	0.564
N	346	87	43	44	43

Note: $*p < .05$, $** p < .01$, $*** p < .001$

Dependent variable is the growth rate of GDP per worker. The year dummies are significant in 1-year estimation of three periods (1993~1994, 1998~1999, and 1999~2000). Corresponding untabulated results are $\beta_{92-93} = -0.017$ ($p < 0.01$), $\beta_{97-98} = -0.017$ ($p < 0.05$), and $\beta_{98-99} = -0.013$ ($p < 0.05$).

Robustness Test

As there may exist correlations of error terms across the consecutive time periods, seemingly unrelated regression (SUR) is performed to obtain more efficient estimates and to examine robustness of the model and two approaches of assessing IT maturity effect. First, Table 6A presents the results of the 4-year growth regression based on the quartile-based maturity model. Similar to OLS results shown in Table 4, the results confirm that countries of Q3 and Q4 began to have increasing returns from IT stock growth in the period 1996-2000. Second, the results of SUR with the externality-based maturity model are presented in Table 6B. The results are also analogous to the test results of OLS estimation in Table 5. In essence, both results from SURs with quartile-based maturity model and externality-based maturity model are consistent and confirm the main findings based on OLS estimates.

Table 6. Result of Seemingly Unrelated Regression (SUR)

A. 4-Year Growth Model with Quartile Groups

	4-Years Growth (1992-1996)	4-Years Growth (1996-2000)
β_K	0.274*** (4.355)	0.257* (2.375)
β_{IT}	0.291*** (6.127)	0.179** (2.668)
$\beta_{IT, Q2}$	-0.128 (-2.730)	0.106 (1.503)
$\beta_{IT, Q3}$	0.027 (0.432)	0.252** (2.786)
$\beta_{IT, Q4}$	-0.003 (-0.034)	0.436** (3.114)
R^2	0.642	0.390
N	43	43

B. 4-Year Growth Model with Externalities Effects

	4-Years Growth (1992-1996)	4-Years Growth (1996-2000)
β_K	0.295*** (4.332)	0.292** (2.815)
β_{IT}	0.295*** (4.332)	0.292** (2.815)
β_{ext}	0.083 (0.212)	1.273*** (3.581)
R^2	0.564	0.397
N	43	43

Note: *p < .05, **p < .01, ***p < .001

Discussion and Conclusions

The long-due discussion about the IT productivity paradox has puzzled researchers during recent decades. So far, most countries have been increasing IT investment in spite of rare evidence of its positive contribution. In fact, without a positive relationship between IT investment and productivity, there would be little reason for countries to pay high rents to adopt IT. However, we find that national productivity growth is positively affected by IT expenditure growth.

The results of the current study provide answers to several fundamental questions about the subject. One, based on the empirical results with the sample data period 1992-2000, we conclude that most countries experience positive returns from IT investment. Two, we attempt to explain the factors that differentiate the elasticity of IT investment. The empirical findings in this study suggest that the magnitude of positive returns to IT investment differ depending on the level of IT maturity. Three, we produce two alternative models with measures for IT maturity to determine whether countries experience different returns from IT investment. Both the quartile-based maturity model and the externality-based maturity model offer insight on the structural mechanism of IT returns.

Using the data of the period 1985-1993, a recent global IT investment study reports that, due to matured IT stocks, developed countries manage to produce positive IT returns, whereas developing countries do not (Dewan and Kraemer 2000). In contrast, the current study provides empirical evidence that IT investment have a positive impact on national productivity for all economies based on the more recent data set of the period 1992-2000. The results imply that the countries may become more productive by investing in information technologies regardless of the economic level of each country.

There are several rationales that support the new findings of positive returns from IT for all countries. One, there is a noticeable difference between the sample periods of the current and prior study. The paradigm shift of information technologies from host-based computing to down-sizing client server computing have made IT affordable to developing countries. Two, price drops of computer hardware and software due to technology spillover between/among countries offer more accessibility to information technologies in the last decade. In these circumstances, conventional economic factors such as GDP level, labor, and capital stock may not be enough to explain innovation phenomena through information technologies.

In order to investigate IT maturity effect, the current study uses a direct measure of IT maturity by considering the accumulated IT investments per worker in an economy. We find that IT maturity assessed by either maturity level or externality is a viable factor that supplies further explanation on IT expenditure-return structure. While most countries experience positive returns from IT investment, the elasticity and amount of returns of each country appear to be different. We empirically find that maturity level is one determinant of elasticity and that both measures individually may determine the unique quantity of positive returns to each country. While we find similarities between two measures, there are differences. One noticeable benefit from IT externalities is that it would be a viable measure when the growth of IT stocks reaches the steady state.

The results of the study provide a set of implications to both policy makers and researchers. For policy makers, IT maturity is a factor that makes IT investment more productive. This is because most information technologies require time and effort to become mature before they pay off. However, the results of this paper do not imply that we should wait for the harvest season to come. One outstanding implication for IT policy makers is, therefore, the importance of the concentration of IT investment. As witnessed in many sample countries, economy of scale is an important factor that increases the efficiency of capital stocks. Along this line to empirical evidence from IT externalities, we learn that the increasing IT concentration is a key factor that increases the IT contribution to national productivity. In addition, according to the results, a country's IT maturity, which can be achieved by developing the IT knowledge base, would be a strategic determinant in increasing the returns from IT investment. As such, IT knowledge creation should naturally be the focus of investment strategy.

On the other hand, our results provide researchers with a new direction in this area. While IT investment and productivity are not generally characterized by a cumulative tradition of research, this paper attempts to build on the fairly substantial body of work devoted to provision of theoretic and systematic evidence of positive returns of IT expenditure at a country level. Furthermore, our empirical results suggest that the maturity level of information technology is a driving factor of increasing national productivity. The empirical evidence is signified by two theoretical measures, maturity by IS expenditure and maturity by externalities. Hopefully, research in the area will further develop the IT investment-productivity mechanism.

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