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Digital Divide and Growth Gap

A Cumulative Relationship

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Abstract

This paper, using a cumulative growth model and a catch-up model, verifies the cumulative relationship between IT investment and economic growth, and then examines whether this relationship enlarges the differences in the economic growth among OECD countries. We observe the following results: first, those countries making a rapid progress in IT capital formulation enhance labour productivity faster than the average OECD member countries. Second, non-IT capital has larger impacts on the economy than IT capital. Third, those countries with relatively lower productivity levels can reduce the gap using knowledge spillovers from advanced countries. Fourth, IT investment and expansion increase labour productivity in OECD member countries. Fifth, countries with a solid infrastructure and skilled human resources increase IT investment even more actively. Lastly, the cumulative relationship between IT investment and productivity is shown to be valid and thus this might enlarge the disparity between countries according to the economic possibilities provided by IT investment.

Keywords: IT, growth gap, cumulative relationship

JEL classification: O3, O4, E2

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I Introduction

Measuring returns on IT investment is a complicated matter due to the fact that such investments are not exogenous, but are influenced by certain economic factors such as national wealth, price level of economic resources, IT infrastructure, etc. As a result, there have been inherent problems to show causality in the models that relate productivity growth to IT investment.

Previous studies on IT impacts on economy have been focused on the unilateral relationship, which is to discover whether IT investment brings about economic growth.[1] They have been interested in examining whether IT investment makes positive contributions to the diffusion of new technology, productivity improvement, reduces unemployment rate, enhances consumer utility, and the positive management outcome. On the other hand, the studies on the IT investment function, which is to identify the factors influencing IT investment, are relatively insufficient.

Kraemer and Dedrick (1994, 2001) present a conceptual hypothesis that there is a cumulative relation between IT investment and economic growth. They argue that IT investment and economic growth are inextricably linked. First, the economic factors, like national wealth, wage rates, IT infrastructure, and the price level of IT products, determine IT investments. Growing national wealth provides the financial resources for IT investments and expands demand for IT products, both in businesses and households. Increases in wages provide a greater incentive for firms to invest in IT, either to replace workers or to improve the productivity of workers. The presence of a high quality information infrastructure and the price competitiveness of IT products promote IT investments to take advantage of the potential capabilities of IT products at lower costs. Since national wealth, wage rates, IT infrastructure, and the price level of IT products are determined by economic growth and productivity improvement, the increased level of economy and productivity can eventually lead to IT investments.

The other half of the virtuous circle is the impact of IT investments on economic growth. The positive economic impacts are driven by lower purchasing costs, reductions in inventories, lower sales and marketing costs, and more efficient production processes. Thus, widespread IT technology diffusion creates possibilities for firms to be equipped with more efficient and effective facilities in production and to be able to reduce cost per unit production. These positive economic impacts result in productivity improvement and economic growth.

The conceptual hypothesis presented by Kraemer and Dedrick (1994, 2001), however, was followed by only a correlation analysis instead of direct estimation with an appropriate model to show the contribution of IT investment to economic growth.

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1 Those researches from various perspectives on the impacts of IT investment on economic growth are as follows: the improvement of productivity (Kraemer and Dedrick 1994 and 1999; Oliner and Sichel 1994; Morrison and Berndt 1990; Loveman 1994; Jeong *et al.* 2001), changes in the labour market (Autor *et al.* 1998; Berndt *et al.* 1992), technological innovation (Gera *et al.* 1997), and the competitiveness of firms (Brynjolfsson 1996; Hitt and Brynjolfsson 1996). For more detailed information on this issue, see Triplett (1999).

This paper embodies the idea proposed by Kraemer and Dedrick (1994, 2001) using a cumulative growth model and catch-up model[2] to characterize the cumulative relationship between IT investment and economic growth, and then to verify whether this relationship enlarges the differences in economic growth among OECD countries.

Hence, the first aim of this paper is to introduce a cumulative growth model for the analysis of mutual dependence relationship between IT investment and economic growth. IT investment leads to improvement of productivity and the increased productivity eventually results in advanced IT infrastructure and other resources for higher IT investment. The second objective of this paper is to examine, using a catch-up model, whether the new technological and economic opportunity from IT investment will augment the differences in growth rates among countries or reduce them. In other words, the possibility will be checked that the presence of a high quality information infrastructure and of skilled human resources in developed countries increases the efficiency of IT investment and thus enlarges the disparity.

This paper performs a relative analysis with OECD country data on the impact of IT investment on economic growth. The impact of IT investment on economic growth in OECD countries and the relationship between IT investment and discrepancy in GDP growth rates among those countries are stressed in the analysis. Contrary to previous studies on the causality relationship between IT investment and economic growth, this paper analyses the cumulative relationships, not only the impact of economic growth on IT investment, but that of IT investment on economic growth. Because of this cumulative relationship, the differences in growth rates among countries will widen or shrink according to the amount of IT investment in each country.

We find the following results. First, those countries making rapid progress in IT capital formulation enhance labour productivity faster than the average OECD member-state. Second, non-IT capital has larger impacts on the economy than IT capital. Third, those countries with a relatively lower productivity level can reduce the gap by utilizing knowledge spillovers from advanced countries. Fourth, our results indicate that IT investment and expansion increase labour productivity in OECD member countries, and that countries with a solid infrastructure and skilled human resources increase IT investment even more actively. This finding has some implications on the continuing debate regarding the productivity paradox. Lastly, the cumulative relationship between IT investment and productivity is shown to be valid and thus this might enlarge the disparity between countries according to the economic possibilities provided by IT investment.

The rest of the paper is organized as follows. The model explaining the relationship between IT investment and economic growth is introduced in section 2. In section 3, the empirical test is performed and the results are explained. Concluding remarks and future study plans are given in section 4.

[2] See Kaldor (1957), Verspagen (1993), and Amable (1993).

2 Empirical model[3]

The model developed here considers two countries according to the technological capabilities as in the Amable (1993) and Verspagen (1993) models. These two countries are assumed to have different levels of knowledge stock so that there are opportunities for spillovers. One is technologically advanced and denoted by *L*. The other is technologically inferior and denoted by *i*.

We construct the following equations, which describe the international knowledge spillovers and their impacts on the domestic economy. In the Equation (1), we define the productivity gap, G_i, between the advanced and inferior countries.[4]

$$G_i = \ln \frac{PRO_L}{PRO_i} \tag{1}$$

Here, the difference in the growth rates is logarithmically specified and represented by the productivity gap.

The productivity of the inferior country *i* (*pro*) in Equation (2) is determined by IT investment, *it*, and knowledge spillovers from the advanced country, as is generally assumed in catch-up theory (Abramovitz 1986; Amable 1993; Verspagen 1993). IT investment, as previously mentioned, is assumed to result in productivity improvement.

Knowledge spillovers in the inferior country (*i*) are dependent not only on technological distance but also on its capabilities to assimilate advanced knowledge. It is assumed that the larger the distance between the current level of technological knowledge and the one to be imitated, the higher the probability to improve its productivity. Technology spillovers, however, will not take place if the capability of the receiving country is too low. Even with a favourable outside condition, rapid economic growth cannot be expected to take place in a country that has laws and regulations that inhibit the assimilation of advanced knowledge and skills. The extent to which a country can apply potential knowledge is not an automatic process but crucially depends upon its social capabilities and absorption capacity to assimilate it. Therefore, the contribution of knowledge spillovers to productivity improvement does not come automatically but is dynamically determined by the amount of knowledge spillovers and absorption capacity to realize it.

Now we assume that the amount of spillovers increases in proportion to the knowledge gap, *G*, and the capability to assimilate advanced knowledge is denoted by parameter χ (Harris 1993; Parente and Prescott 1994). χ consists of two components. The first component is the absorptive capacity and dependent on SOC, education system, and policy. Second is an institutional barrier such as a law or regulation banning the adoption of foreign advanced technologies.

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3 Our model is heavily inspired by Amable (1993).

4 See Verspagen (1993). In the model, the capital letter represents a level and the lower-case letter represents the growth rate, respectively.

IT investment (*it*) as in Equation (3) is a function of the productivity level because increases on the demand side through productivity improvement will eventually call for more IT investment (Amable 1993). Under this cumulative growth model, IT investment leads to productivity improvement and the increased productivity results in higher IT investment constructing the virtuous relationship. IT investment as in Kraemer and Dedrick (1994, 2001) depends upon the level of properly established human capital (*sec*). The higher level of human capital leads to an increase in IT investment with a higher rate of return. The higher wage rates, *rw*, provide a greater incentive to invest in IT, either to substitute labour or to improve productivity in order to sustain them. It is also possible that an increase in wages has negative impacts on IT investment through lower profits.

Human capital in Equation (4) depends on productivity gap, *G*, implying the level of technological development. It is assumed that the rate of enrolment in secondary school (*sec*) is a function of primary school enrolment rate (*prim*) (Amable 1993). Finally, in the Equation (5), λ represents the level of wage—labour nexus and results in the following cases as in the theory of regulation (Boyer 1988: 1) This is the case where wage and productivity growth have a peristaltic movement and wage rate is determined by institutional compromise. In this case, λ converges to 1; 2) On the other hand, in the case where the wage rate is determined by demand and supply curves in the labour market instead of institutional compromise, λ converges to 0.

$$pro_i = \beta_0 + \beta \cdot it_i + \chi \cdot G_i \tag{2}$$

$$it_i = \varepsilon \cdot pro_i + \phi \cdot \sec_i + \varphi \cdot rw_i + \varepsilon_0 \tag{3}$$

$$\sec_i = -\gamma \cdot G_i + \eta \cdot prim_i + \gamma_0 \tag{4}$$

$$rw_i = \lambda_0 + \lambda \cdot pro_i \tag{5}$$

The Equations (2)-(5) yield the following Equation (6).

$$\begin{aligned} pro_i = {} & \frac{1}{1-\beta\varepsilon-\beta\varphi\lambda}(\beta_0 + \beta\varepsilon_0 + \beta\phi\gamma_0 + \beta\varphi\lambda_0 + \beta\phi\eta \cdot prim_i) - \frac{\beta\phi\gamma}{1-\beta\varepsilon-\beta\varphi\lambda} G_i \\ & + \frac{\chi}{1-\beta\varepsilon-\beta\varphi\lambda} G_i \end{aligned} \tag{6}$$

As we can see in Equations (7)-(10), the advanced country has the same movement as the inferior one, except in Equation (7) and (9). Since the productivity gap *G* is 0, there are no such effects in Equations (7) and (9).

$$pro_L = \mu_0 + \mu \cdot it_L \tag{7}$$

$$it_L = \pi \cdot pro_L + \varpi \cdot \sec_L + \theta \cdot rw_L + \pi_0 \tag{8}$$

$$\sec_L = \vartheta \cdot prim_L + \vartheta_0 \tag{9}$$

$$rw_L = \rho_0 + \rho \cdot pro_L \tag{10}$$

Equations (7)-(10) are summarized in Equation (11):

$$pro_L = \frac{1}{1-\mu\pi-\mu\theta\rho}(\mu_0 + \mu\pi_0 + \mu\varpi\vartheta_0 + \mu\theta\rho_0 + \mu\varpi\vartheta \cdot prim_L) \tag{11}$$

Equation (1) yields the following Equation (1´) to represent the changes in productivity gap ($\dot{G}$)[5].

$$\dot{G}_i = pro_L - pro_i \tag{1´}$$

From Equation (1´), Equation 6, and Equation (11), dynamics of the productivity gap among countries can be summarized as follows:

$$\dot{G}_i = A + B \cdot G_i - C \cdot G_i \tag{12}$$

where

$$\begin{aligned} A = & \frac{1}{1-\mu\pi-\mu\theta\rho}(\mu_0 + \mu\pi_0 + \mu\varpi\vartheta_0 + \mu\theta\rho_0 + \mu\varpi\vartheta \cdot prim_L) \\ & - \frac{1}{1-\beta\varepsilon-\beta\varphi\lambda}(\beta_0 + \beta\varepsilon_0 + \beta\phi\gamma_0 + \beta\varphi\lambda_0 + \beta\phi\eta \cdot prim_i) <> 0 \end{aligned} \tag{13}$$

$$B = \frac{\gamma\beta\phi}{1-\beta\varepsilon-\beta\varphi\lambda} > 0$$

$$C = \frac{\chi}{1-\beta\varepsilon-\beta\varphi\lambda} > 0$$

$0 < (\mu\pi + \mu\theta\rho) < 1$ and $0 < (\beta\varepsilon + \beta\varphi\lambda) < 1$ [6]

Searching for equilibrium values of the productivity gap, Equation (12) is set to zero. This yields the following equation.

$$A + B \cdot G_i = C \cdot G_i \tag{14}$$

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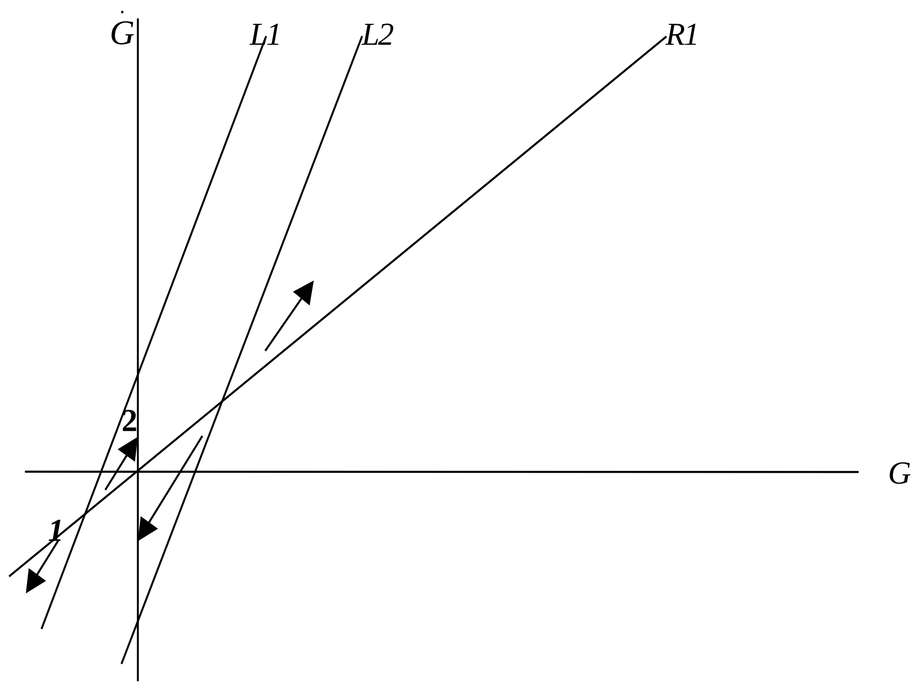
5 $\dot{G} = \frac{dG}{dt}$. $\dot{G}$ stands for the changes in productivity gap.

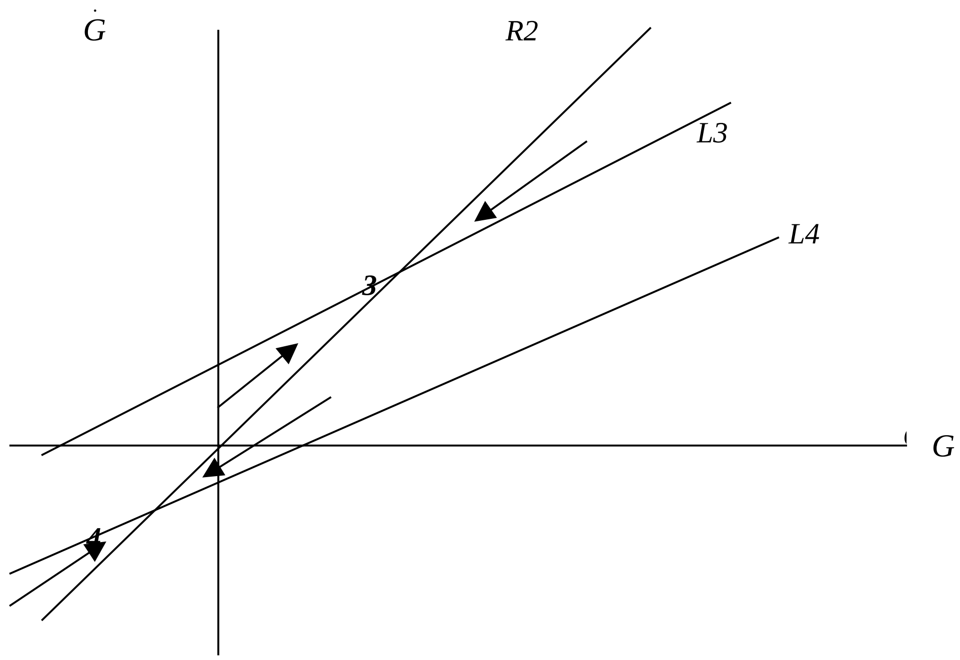
6 This condition should be satisfied to keep the system stable from the cumulative and self reinforcing effects which are raised by the mutual interaction between IT investment and productivity. See Dixon and Thirlwall (1975) and Verspagen (1993) for more detailed explanation.

Figure 1
The dynamics of the productivity gap

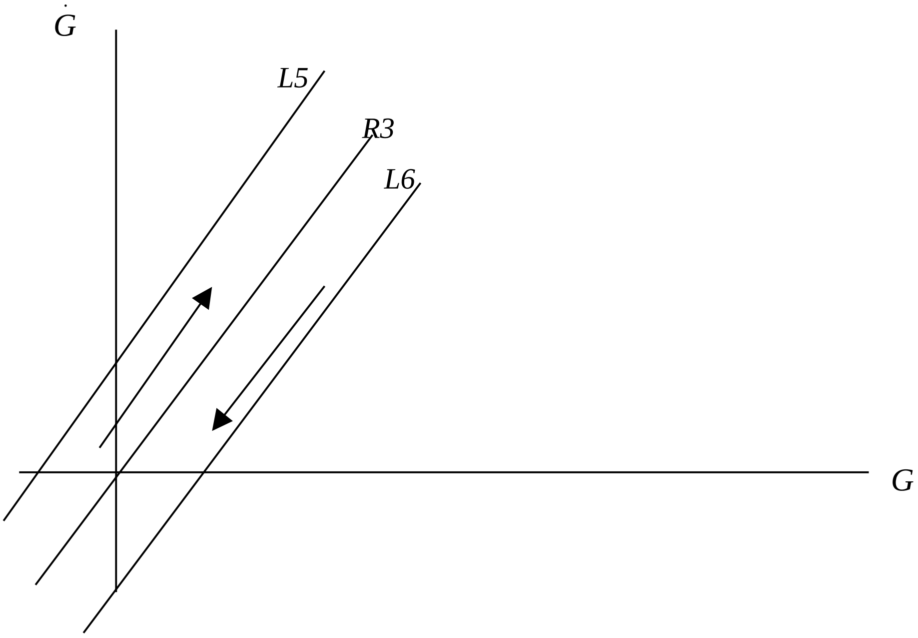
1-i) C < B: $\gamma\beta\phi > \chi$



1-ii) C > B: $\gamma\beta\phi < \chi$



1-iii) *C=B:* $\gamma\beta\phi = \chi$



The straight line denoted by *L* represents the left-hand side of Equation (14), while the line labelled by *R* corresponds to the right-hand side of the equation. Where the line *R* is below the line *L*, the productivity gap grows, since the amount of the spillover flowing to the inferior country is smaller than the increase in the productivity gap determined by other factors in the model (i.e. the IT and human capital stocks, etc.). On the other hand, where the line *R* is above the line *L*, the productivity gap becomes smaller.

There are three possible situations in Equation (14) and Figure 1. First, in the case of (1-i), the level of human capital stock in the inferior country is insufficient and the impact of knowledge spillovers on the productivity of the inferior country is small. In other words, shortcomings from the low level of human capital stock in the inferior country have larger impacts on the productivity growth than knowledge spillovers would have. There are two different cases here according to the level of productivity development due to other factors such as IT stock, and other exogenous variables with positive impacts on productivity: (*L1*) is the case in which the impacts of other factors on productivity are smaller in the inferior country than in the advanced country and (*L2*) is the opposite. There is an equilibrium point 1 in *L1*. The initial state at the left-hand side of the equilibrium (1) does not exist since the advanced country always has a higher level of productivity. On the other hand, a small deviation from this equilibrium point to the right will result in a growth of the productivity gap. With a small contribution of knowledge spillovers as well as the other factors, it will lead the inferior country away from catching-up. In the case of an initial point somewhere at the left-hand side of equilibrium (2), the inferior country will be able to improve its productivity and catch up with the advanced country due to other factors.

In the second case of (1-ii), regardless of the initial productivity discrepancy, the system will converge to the equilibrium point 3 with a small impact of knowledge spillovers on productivity growth. When the inferior country has an assimilating capability as in *L4*, it will be able to catch up with the advanced country regardless of the initial state. Lastly, 1-iii is the case where the negative impacts from the low level of human capital stock in the inferior country have the same size as the positive ones from knowledge spillovers. In this case, the trend of the productivity gap is totally determined by the other factors in the model. If the other factors' contribution to the productivity growth is smaller in the inferior country than in the advanced country, productivity gap will keep increasing. In the opposite case of *L6*, the inferior country will be able to catch up the advanced country regardless of the initial gap.

3 Data sources and results

3.1 Data sources

We perform a panel analysis with the cross section and time series, pooling data from seventeen OECD member countries over the period 1991-97. The data for our analysis are from OECD database and include GDP, labour force, IT investment and fixed capital formulation, government expenditure, and the rates of enrolment in the primary and secondary schools.[7]

To estimate the result, a regression model is developed as shown below:

$$y_{it} = a_{1i} + \sum_{k=2}^{K} a_k x_{kit} + e_{it} \tag{15}$$

i = 1,2,…N, t = 1.2, …T,

where y_{it} and x_{kit} are the dependent and independent variables, respectively, combined with N observations in cross section data and T observations in time series data. The constant term is a_{1i} and e_{it} is assumed to be a random error with 0 mean and σ^2 variance.

It is preferable to use the random effect model to estimate Equation (15) rather than the fixed effect model since the former improves the efficiency in the model. However, the random effect model tends to raise the model specification error problem unless μ_i and x are independent. Following Hausman specification test, we use the random effect model if the null hypothesis of no correlation between μ_i and x is not rejected. Otherwise, the fixed effect model is used for our empirical results.

7 IT investment data from OECD (1999) include IT hardware, IT services and software, and telecommunication services. The 17 OECD member countries include Greece, Netherlands, Norway, US, Belgium, Switzerland, Spain, Ireland, UK, Australia, Japan, Canada, Austria, Portugal, France, Finland, and Korea.

4 Empirical results

In this paper, we examine not only the cumulative relationship between IT investment and productivity growth, but correspondingly also generate the productivity gap among countries.

4.1 IT investment and productivity gap

We obtain the following equations from Equation (12) in order to examine the role of IT investment in generating productivity gap among countries.

$$\dot{G} = a + b \cdot G \qquad \text{(A)}$$

$$\dot{G} = c + d \cdot it \qquad \text{(B)}$$

In Equation (A) and (B), the value $\dot{G}$ is obtained by subtracting the labour productivity growth rate of the individual country from the average value of the OECD member countries. It represents the gap of productivity growth among countries. In Equation (A), its minus value implies that the productivity growth rate of the individual country increases faster than the average rate of OECD member countries.[8] We add non-IT capital and human capital to these two equations and examine the parameter value of each variable. Table 1 presents our empirical results.

The estimated results from the random effect model have been used for all equations, since the null hypothesis of no correlation between μ_i and independent variables is not rejected at the 10 per cent confidence level in Hausman specification test. The R^2 of 0.27~0.41, a useful measure of fitness, allows us to conclude that it is associated with a good fit of our model regardless of the panel data pooled with cross section and time series data.

Our empirical results indicate that the estimated coefficients of the growth rate of IT and non-IT capital stocks and productivity gap have negative signs with statistical significance as predicted. On the other hand, the estimated coefficient of human capital, which implies the assimilating capability of the individual country, has a minus sign with no statistical significance. The key implications from our empirical results can be presented as follows.

First, the empirical result from estimated Equation (1) indicates that an economy with a higher level of IT investment grows faster than the average OECD member-state. In other words, the productivity gap among countries decreases as IT investment grows.

Second, it is shown that both IT and non-IT capital stocks play an important role in reducing the productivity gap among OECD member countries. Estimated Equation (3) generated by including non-IT capital stock in Equation (1) shows higher value of R^2

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8 We calculated the values of IT capital stock and total capital stock from fixed capital formulation and IT investment data in OECD DB. And we obtain non-IT capital stock by subtracting IT capital stock from total capital stock.

and goodness of fit. It is worth pointing out that non-IT capital stock plays a bigger role in reducing the productivity gap than IT stock, since our estimation yields IT capital stock coefficients of -0.14 and non-IT capital stock coefficient of -0.23, respectively. This result is in accordance with Kraemer and Dedrick (2001), who analysed data from 46 countries during the period of 1985 to 1995.

Lastly, the estimated coefficient of productivity gap *G*, which represents the spillover effects, shows a minus sign with statistical significance in estimated Equations (2) and (6). This result indicates that the countries with a relatively low level of productivity among OECD nations grow faster, by utilizing the knowledge spillovers from advanced countries. This result also accords with those from Verspagen (1993) and Amable (1993), who performed empirical analysis on the catch-up theory and verified that inferior countries reduced the gap by using the knowledge from advanced countries as well as their own know-how.

Table 1
The estimated results from reduced equations

Estimated equation	Constant	*it*	*G*	*K*	*sec*	R^2	Hausman test	*n*
1	-2.23***	-0.16***					χ^2 (1) = 0.07	
	(0.05)	(0.44)				0.27	(0.80)	113
2	-2.73***		-0.04***				χ^2 (1) = 0.61	
	(0.33)		(0.11)			0.36	(0.43)	113
3	-1.86***	-0.14***		-0.23***			χ^2 (2) = 4.7§3	
	(0.42)	(0.05)		(0.06)		0.42	(0.09)	113
4	-1.39	-0.17***			-0.03		χ^2 (2) =3.04	
	(1.39)	(0.05)			(0.05)	0.29	(0.21)	89
5	-0.73	-0.14***		-0.23***	-0.04		χ^2 (3) = 6.01	
	(1.32)	(0.05)		(0.07)	(0.05)	0.41	(0.11)	89
6	-0.97	-0.11*	-0.03*		-0.04		χ^2 (3) = 3.83	
	(1.38)	(0.06)	(0.02)		(0.05)	0.38	(0.28)	89

Notes: 1) Standard errors in parenthesis.
2) *it* = growth rate of IT capital stock per capita; *G* = productivity gap; *K* = growth rate of non-IT capital stock per capita; *sec* = secondary education enrolment ratio.
3) ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

4.2 The cumulative relationship between IT investment and productivity growth

We estimated the cumulative growth model of Equation (2)-(5) using three-stage least square regression and the results are presented in Table 2. Productivity function, human capital function, and real wage growth function are estimated in the simultaneous equation form to show the cumulative relationship between IT investment and productivity growth.

Table 2
The estimated results from simultaneous equations

$$pro = 39.47 + 1.20\,it + 0.23\,G - 2.70\,gov$$
(1.39) (2.25**) (1.74*) (-1.40)

RMSE = 3.25

$$it = -11.46 + 3.88\,pro - 2.26\,rw + 0.61\,sec - 0.95\,r$$
(-1.18) (2.87***) (-1.61*) (1.62*) (-1.65*)

RMSE = 8.07

$$sec = 17.58 - 0.06\,G + 0.38\,pri$$
(5.12***) (-1.56) (2.3**)

RMSE = 1.44

$$rw = 0.04 + 0.30\,pro$$
(0.04) (1.7*)

RMSE = 1.84

Notes:
1) t values are enclosed in parenthesis.
2) *pro* = growth rate of labour productivity; *it* = growth rate of IT capital stock per capita; *G* = productivity gap; *gov* = government expenditure/GDP; *rw* = growth rate of real wage; *sec* = secondary education enrolment ratio; *r* = interest rate; *pri* = primary education enrolment ratio.
3) ***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively.
4) Three stage least squares regression is used for this estimation.

In the first equation of productivity function, the estimated coefficients of IT investment and productivity gap have positive signs as predicted and are statistically significant. On the other hand, the estimated coefficient of government expenditure has a minus sign with no statistical significance.[9] This result is similar to the one from the reduced equation and implies that IT investment with knowledge spillovers increases an individual country's productivity.

With regard to the variables in the second equation of the IT investment function, the estimated coefficients of productivity growth and human capital show positive signs as predicted and those of real wage growth and interest rates have negative signs. Among these variables, the estimated coefficients of productivity growth and interest rate are statistically significant at the 10 per cent significance level.[10] This is consistent with the results from Kraemer and Dedrick (2001) in the sense that investment for IT capital

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9 Following Barro (1991), we also assume that government expenditure (*gov*) has negative effect on productivity growth since most government expenditures consist of unproductive areas like national defence.

10 In the estimated equation for IT capital growth, the coefficients for real wage and secondary education enrolment ratio are statistically significant at 10.8 per cent and 10.6 per cent, respectively.

increases as market demand expands with sufficient human capital and low interest rate. In other words, we find evidence that IT capital accumulates favourably under an economic environment with low financial cost and sufficient human capital. Turning to the estimated coefficient of real wage growth, our result is inconsistent with Kraemer and Dedrick (2001) and shows negative sign to imply that an increase in the wage rate results in smaller profits and thus a decrease in IT investment. One explanation for this inconsistency is that a decrease in profits through an increase in the wage rate has larger effects on IT investment than those from labour force substitution.

The third equation of human capital function is determined by the productivity gap and primary education enrolment rate. The estimated coefficients of the primary education enrolment rate and productivity gap show positive and negative signs, respectively, as predicted. The estimated coefficient of the former is statistically significant, but that of the latter is not.

Lastly, real wage function is determined by the productivity level and the estimated coefficient shows a positive sign with statistical significance, as predicted. The estimated value of coefficient is relatively low at 0.3, which represents a flexible labour market since 1980s.[11]

5 Concluding remarks

Using an empirical analysis with data on OECD member countries over the 1990s, this paper examines the impact of IT investment on the productivity gap between countries and the cumulative relationship between IT investment and productivity. Our reduced and simultaneous equation models are estimated and indicate the following results.

First, those countries making rapid progress in IT capital formulation enhance labour productivity faster than the average OECD member country. Second, non-IT capital has larger impacts on the economy than IT capital. Third, countries with a relatively lower productivity level can reduce the gap using knowledge spillovers from advanced countries. Fourth, our results indicate that IT investment and expansion increase labour productivity in OECD member-states and that countries with a solid infrastructure and skilled human resources increase IT investment even more actively. This finding provides some implications on the continuing debate regarding productivity paradox. Lastly, the cumulative relationship between IT investment and productivity is shown to be valid and thus this might widen the disparity between countries according to the economic possibilities provided by IT investment.

There have been extensive research results from various perspectives on the impacts of IT investment on the economy. But most previous studies examining IT impacts on the economy have focused on the unilateral relationship, which is to discover whether IT investment brings about positive economic results such as higher economic growth, the

11 As Boyer (1988) indicates, wage formation constitutes with productivity growth. Its estimated value is close to 1 before 1980s. On the other hand, the flexible labour market in the 1980s attenuates the intimate relationship between productivity growth and real wage.

diffusion of new technology, productivity improvement, reduced unemployment rate, enhanced consumer utility, and the positive management outcome, etc. On the other hand, the studies on IT investment, which aim to identify the factors influencing IT investment, are relatively rare.

The cumulative relationship between IT investment and productivity shown in this paper introduces some valuable implications since the disparity in IT can be considered as a primary factor in creating the unequal economic growth among countries as well as between generations and regions. Because of this cumulative relationship, differences in growth rate among countries will accumulate or shrink according to the amount of IT investment in each country. Judging from this result, government efforts to build a high quality IT infrastructure and skilled human resources in developing countries will increase the efficiency of IT investment and thus promote its impacts.

References

Abramovitz, M. A. (1986). 'Catching Up, Forging Ahead and Falling Behind'. *Journal of Economic History*, 46: 79-89.

Amable, B. (1993). 'Catch-up and Convergence: A Model of Cumulative Growth'. *International Review of Applied Economics*, 7: 1-25.

Arrow, K. J. (1994). 'The Production and Distribution of Knowledge', in G. Silverberg and L. Soete (eds), *The Economics of Growth and Technical Change*. Aldershot: Edward Elgar.

Arthur, B. (1988). 'Competing Technologies: An Overview', in G. Dosi, C. Freeman, R. Nelson, G. Silverberg, and L. Soete (eds), *Technical Change and Economic Theory*. London: Pinter Publishers.

Autor, D. *et al*. (1998). 'Computing Inequality: Have Computers Changed the Labor Market?'. *The Quarterly Journal of Economics*, November: 1169-213.

Berndt, E. *et al*. (1992). 'High-Tech Capital, Economic and Labor Composition in US Manufacturing Industries: An Explanatory Analysis'. NBER Working Paper No. 4010. Cambridge, MA: National Bureau of Economic Research.

Boyer, R. (1988). 'Formalizing Growth Regimes, in G. Dosi *et al*. (eds), *Technical Change and Economic Theory*. London: Pinter Publishers.

Bresnahan, Timothy F. (1999). 'Computerisation and Wage Dispersion: An Analytical reinterpretation'. *Economic Journal: The Journal of the Royal Economic Society*, 109 (456): F390-F415.

Brynjolfsson, E. (1996). 'The Contribution of Information Technology to Consumer Welfare'. *Information Systems Research*.

Chennells, Lucy, and John Van Reenen (1999). 'Has Technology Hurt Less Skilled Workers? An Econometric Survey of the Effects of Technical Change on the Structure of Pay and Jobs'. Working Paper Series No. W99/27. London: The Institute for Fiscal Studies.

Dewan, Sanjeev, and Kenneth L. Kraemer (2000). 'Information Technology and Productivity: Preliminary Evidence from Country-Level Data'. *Management Science*, 46 (4): 548-62.

DiNardo, John E., and Jorn-Steffen Pischke (1997). 'The Returns to Computer Use Revisited: Have Pencils Changed the Wage Structure too?'. *Quarterly Journal of Economics*, 112 (1): 291-303.

Dixon, R., and A. Thirlwall (1975). 'A Model of Regional Growth-Rate Differences on Kaldor Lines'. *Oxford Economic Papers*, 11: 201-14.

Foray, D., and B. Lundvall (1996). 'The Knowledge-based Economy: From the Economics of Knowledge to the Learning Economy', in OECD (eds) *Employment and Growth in the Knowledge-based Economy*. Paris: OECD.

Freeman, C. (1994). 'Technological Revolutions and Catching-Up: ICT and the NICs', in J. Fagerberg, B. Verspagen, and N. von Tunzelmann (eds), *The Dynamics of Technology, Trade and Growth*. Aldershot: Edward Elgar.

Freeman, C. (1987). 'Information Technology and Change in Techno-Economic Paradigm', in C. Freeman and L. Soete (eds), *Technical Change and Full Employment*. Oxford: Basil Blackwell.

Gera, S. *et al*. (1997). 'Information Technology and Productivity Growth: An Empirical Analysis for Canada and the United States'. Paper prepared for CSLS Conference.

Harris, D. (1993). 'A Model of Productivity Gap: Convergence or Divergence?', in R. Thomson (ed.), *Learning and Technological Change*. New York: St. Martin's Press.

Hitt, L., and E. Brynjolfsson (1996). 'Information Technology and Internal Firm Organization: An Exploratory Analysis'. *Journal of Management Information Systems*, 14: 81-101.

Kaldor, N. (1957). 'A Model of Economic Growth'. *Economic Journal*, 57: 591-624.

Kraemer, Kenneth L., and Jason Dedrick (1994). 'Payoffs from Investment in Information Technology: Lessons from Asia-Pacific Region'. *World Development*, 22 (12): 1921-31.

Kraemer, Kenneth L., and Jason Dedrick (2001). 'Information Technology and Productivity: Results and Implications of Cross-country Studies', in M. Pohjola (ed.), *Information Technology and Economic Developm*ent. Cambridge: Oxford University Press.

Krugman, P. (1999). 'Digital Technology and the Productivity Paradox: After Ten Years, What has been Learned?'. Mimeo.

Loveman, G. (1994). 'An Assessment of the Productivity Impact of Information Technologies', in T. Allen (ed.), *Information Technology and the Corporation of the 1990s: Research Studies*. Oxford: Oxford University Press, 84-110.

Morrison, C. J., and E. R. Berndt (1990). 'Assessing the Productivity of Information Technology Equipment in the US Manufacturing Industries'. NBER Working Paper, No. 3582. Cambridge, MA: National Bureau of Economic Research.

Nelson, R., and E. Phelps (1966). 'Investment in Humans, Technical Diffusion and Economic Growth'. *American Economic Review*, 56: 66-75.

OECD (1999). *OECD Science, Technology and Industry Scoreboard*. Paris: OECD.

OECD (1996). *Employment and Growth in the Knowledge-based Economy*. Paris: OECD.

Jeong, K, J. Oh, and I. Shin (2001). 'The Economic Impact of Information and Communication Technology in Korea', in Matti Pohjola (ed.), *Information Technology, Productivity, and Economic Growth*: *International Evidence and Implications for Economic Development.* Oxford: Oxford University Press.

Oliner, S., and D. Sichel (1994). 'Computers and Output Growth Revisited: How Big Is the Puzzle?'. *Brookings Papers on Economic Activity*, 2: 273-334.

Parente, S., and E. Prescott (1994). 'Barriers to Technology Adoption and Development'. *Journal of Political Economy*, 102: 298-321.

Pohjola, Matti (2001). 'Information Technology and Economic Growth: A Cross-Country Analysis', in M. Pohjola (ed.), *Information Technology and Economic Developm*ent. Oxford: Oxford University Press, 242-56.

Romer, P. (1990). Endogenous Technological Change'. *Journal of Political Economy*, 98: S71-S102.

Shapiro, C., and H. Varian (1999). *Information Rules*: *A Strategic Guide to the Network Economy.* Cambridge, MA: Harvard Business School Press.

Triplett, J. (1999). 'The Solow Productivity Paradox: What Do Computers Do to Productivity?'. *Canadian Journal of Economics*, 32 (2): 309-34.

Tyson, L. (1999). 'Old Economic Logic in the New Economy'. *California Management Review*, 41 (4).

US Department of Commerce (1999). *The Emerging Digital Economy*. Washington, DC: Secretariat for Electronic Commerce.

US Department of Commerce (1998). *The Emerging Digital Economy*, II. Washington, DC: Secretariat for Electronic Commerce.

Verspagen, B. (1993). *Uneven Growth Between Interdependent Economies*. Aldershot: Avebury.

Young, A. (1928). 'Increasing Returns and Economic Progress'. *Economic Journal*, 38: 527-42.