The Role of IT, R&D in Industrial Productivity Growth: Evidence from Korea

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ABSTRACT: A large body of literature attempted to examine the importance of Information and Communication Technology (IT) on the economic growth. This study tests the hypothesis that the IT investment has a positive impact on productivity growth at the industrial level. We use IT and R&D as explanators of variation in productivity. To test our hypothesis, we employ panel data analysis on a cross-section of 16 industries and a time period of 15 years. Our results confirm the positive effect of IT and R&D produce on productivity. However, the positive contribution of IT is confined only to the IT-intensive industry, which implies certain policy measures should be developed to enforce the positive externalities of IT investments to the non-IT-intensive industries.

Ⅰ. Introduction

IT (Information and Communication Technology) has been considered as one of the major driving forces, which altered the nature of the world economic growth since 1980's. It has been generally accepted that these changes came from the radical technological innovation brought about by the developments in the IT sector as well as by the structural changes of production and consumption patterns in nearly all of the other industries related to changes in IT. However, some researchers reported that the modification of industrial structure due to IT developments is only limited to the developed countries[1]. That implies that more fundamental changes in the industrial structure are

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[1] See, Dewan and Kreamer (2000), Kim, J.S. (2001)

needed in order for the IT investments to become the driving force of the overall economic growth. Up until now, it was found that the relationship between the IT investment and productivity growth was not significant in the Korean industrial sector that is classified as that of a developing economy (Lee and Kim (2000) and Bank of Korea (2000)).

It appears that the relative importance of IT investment in production is very small and that the spillover effects from IT are negligible[2]. According to the results of Lee (2001), Kim and Lee (2001), although there is some evidence on the positive correlation between the IT investment and productivity growth of the manufacturing sector, the productivity paradox seems to persist in the service industry in Korea. These results are similar to those of McGuckin and Stiroh (1998), Stiroh (2001) for the case of the U.S. and imply that the spillover effects of IT can vary over different industries.

However, the research on spillover effects of IT based on the estimates of the IT capital stock at the industrial sector level has not yet been widely performed, the difficulties in obtaining such estimates being one essential reason. In this study we employ such estimates for the Korean case that were constructed recently by Lee and Kim (2000), Kim and Lee (2001). The analysis of IT effects at the industry level allows for a more disaggregate analysis and as such for more reliable conclusions. In addition, panel data analysis of industry level data makes the cross-verification of the results to be possible by using two different models, fixed effect and random effect model.

This study reports the results of a panel data analysis on the relationship between IT investment and productivity growth of various industries based on the IT capital stock, which the authors have estimated previously. In addition, we analyzed the relationship between productivity growth and R&D, which is one of the main factors defining the knowledge–based society. We use labor productivity of each industry as the dependent variable. In addition, in our panel data analysis, we estimated both fixed and random effect models.

This paper is organized as follows. In section 2, we describe the key concepts of a knowledge-based society. In section 3, we develop a model, which analyzes the relationship between the productivity growth and IT and R&D capital stocks. In section 4, we report the results, and section 5 derives policy implications.

[2] Sichel (1997) reported that the amount of capital stock related to computers is only 2% in total capital stock and contradicted the insistence of the productivity growth by the fast accumulation of IT capital stock.

II. The Key Concepts of a Knowledge-Based Society.

The analysis of economic returns from IT investments was generally performed at the firm-, industry- and country level. At the firm level, the analysis focused on whether the IT expenditure contributes to the profit increase in the individual firms. Brynjolfsson and Hitt (1995, 1998), Lucas (1999) emphasize the organizational modification and conversion efficiency in lifting the effectiveness of IT investments. At the country-level, Kreamer and Dedrick (1999), Dewan and Kreamer (2000), Kim (2000) reported that investment on IT played significant roles in economic growth in developed countries. However, its role in developing countries has not been significant or even adversely affected in their economic growth.

The industry-level analysis of IT's effect is devoid of the bias produced by the loss of information at the sector level. In addition, the particular policy implications derived from the analysis performed at the level of individual sectors are also more sector-specific. However, this type of analysis for the relationship between IT investments and the economic returns has not yet been widely performed compared to the firm- and country level studies, the reason being the difficulties in constructing the sector-level data on IT investment and capital stock except for the U.S.

In the case of U.S., Siegel and Grilliches (1991), Sichel (1997), Jorgenson and Stiroh (2000), have examined the positive and statistically significant role of information and telecommunication investment in productivity growth of industrial sectors. Berndt and Morrison (1995) find some evidence that industries with a higher proportion of high-tech capital (esp. IT) have higher measures of economic performance. In the case of Korea, the effect of IT investment on productivity growth was analyzed by dividing all industries into the IT-intensive and non-IT-intensive industries, which was done by the Bank of Korea (2000). The Bank's report provides estimates of the contribution of IT to the TFP growth suggesting that the positive and significant effects of IT can only be found in IT-intensive-using industries.

In the analysis of IT's role in productivity growth at the industry level, the major difficulty is the estimation of IT capital stock. This study develops the analysis of IT's role at the industry level based on the estimates in Korea by Lee and Kim (2000) and Kim and Lee (2001). In our analysis, we consider IT and R&D as alternative explanators for improvements in industrial productivity.

R&D has long been accepted that it contributes to the national competitiveness and enhances the productivity growth based on various theoretical and empirical studies. It has the similarities with IT in the following factors. First, the IT investment produces positive externalities in the form of the spillover effects, as Oliner and Sichel (1994) pointed out. Therefore, the difference between private and social returns to IT investments can exist, leading to the problem of under-investment into the IT sector if this difference is not internalized. In addition, the problem of measuring the effects of investment, the time lag between the event of investments and the realization of their economic returns, the importance of the provision of the supporting infrastructure and human capital simultaneously with the IT investments and the depreciation of their economic value are common issues to both the IT and R&D investment.

In this study, we expand and apply the basic framework of R&D analysis to IT focusing on the above points of similarity. In other words, we interpret these capital stocks as proxy variables, which represent the level of knowledge application (R&D) and information usage (IT).

III. Model

We define the production function as follows in order to simultaneously analyze the effects of both R&D and IT on productivity:

$$Y = f(K, L \mid RD, IT, t) \tag{1}$$

We assume here that each industry has R&D capital stock (RD), IT capital stock (IT), and the level of technology development producing value added (Y) with capital (K) and labor (L). We follow the basic framework of analyzing the returns from R&D adding IT as another explanatory of growth in productivity. We assume the Cobb-Douglas production function:

$$\ln Y_{it} = A + \lambda_t + \alpha_L \ln L_{it} + \alpha_K \ln K_{it} + \gamma_{RD} \ln RD_{it} + \gamma_{it} \ln IT_{it} + \nu_i + \varepsilon_{it} \tag{2}$$

where $i = 1, \ldots, N$ represents specific industries, $t = 1, \ldots, T$ represents time. RD and IT represent the absolute level of R&D and IT capital stock, respectively, α_L, α_K represent marginal elasticity of labor and capital in production and γ_{RD}, γ_{IT} represent marginal elasticity of R&D and IT in production, respectively. ν_i is the term representing industry-specific effects without any time effects and ε_i is white noise. In our analysis, we assume constant returns to scale in production from labor and capital ($\alpha_L + \alpha_K = 1$) in order to focus on the estimation and analysis of γ_{RD}, γ_{IT} which represent excess returns to R&D and IT capital stocks.

$$\ln TFP_{it} = \ln(Y / L^{1-\alpha_L} K^{\alpha_K}) = A + \lambda_t + \gamma_{RD} \ln RD_{it} + \gamma_{IT} \ln IT_{it} + \nu_i + \varepsilon_{it} \tag{3}$$

$$\ln LFP_{it} = \ln(Y/L) = A + \lambda_t + \alpha_K \ln(K/L)_{it} + \gamma_{RD} \ln RD_{it} + \gamma_{IT} \ln IT_{it} + v_i + \varepsilon_{it} \qquad (4)$$

Throughout equation (1) to (3), parameters α_K, γ_{RD}, and γ_{IT} are identical in all three equations. The reason for this particular parameterization comes from the fact that the three equations are numerically same. The choice of equations depends on the parsimoniousness of the estimation or the advantage of interpretability. γ_{RD} and γ_{IT} represent additive increases in production with the increase of R&D and IT capital stock *ceteris paribus.* In this study, we report the estimation results of equation (3) based on the preliminary estimation of three equations considering the statistical reliability**.**

In our empirical analysis, we take into account differences between industrial sectors as well as the time lag. When pooling the data, thus neglecting the sector-specific differences, we find our estimates to be statistically significant. However, our estimates from the pooled data neglect differences in cost and production structure, basic technologies and specific internal structure among industrial sectors. In order to overcome this problem, we further implemented the panel data analysis. In the panel data analysis, we can estimate cross-sectional heterogeneities by using fixed- and random effects models.

In the fixed effect model, v_i are the dummy variables, which represent individual industrial sector effects. However, the terms are transformed into the form of deviation from the means of each industry. We can represent the within-effects model as follows:

$$\begin{aligned}\ln LFP_{it} - \ln LFP_i = \ln(Y/L) = A + \lambda_t + \alpha_K \{\ln(K/L)_{it} - \ln(K/L)_i\} \\ + \gamma_{RD}\{\ln RD_{it} - \ln RD_i\} + \gamma_{IT}\{\ln IT_{it} - \ln IT_i\} + \varepsilon_{it} - \varepsilon_i \qquad (5)\end{aligned}$$

If we estimate the within-industries regression function with OLS (Ordinary Least Squares), then it is the LSDV (Least Square Dummy Variable) model.

In case of the random-effect model, variables v_i, which are in the composite error term $w_{it} = v_i + \varepsilon_{it}$, are random disturbances that represent the individual industrial sectors' effects without having the time effect in them. Therefore, we use the GLS (Generalized Least Squares) method for estimating the random effects model in order to consider the non-spherical form of the error term. Both regression models are useful in analyzing the relatively short- and medium-term relationships between production or performance and R&D or IT investment. On the other hand, we can use the between-industries regression in order to analyze the long-term relationship between them. In the case of between-industries regression, cross-sectional variations are focused among the variables as follows:

$$\ln LFP_t = A + \lambda_t + \alpha_K \ln(K/L)_i + \gamma_{RD} \ln RD_i + \gamma_{IT} \ln IT_i + \nu_i + \varepsilon_i \quad (6)$$

The above equation is to be estimated by the OLS and the number of cross-sectional industries equals to the number of observations.

IV. Data

1. IT & R&D Capital Stock

In this study, we use the revised IT capital stock of Korean industries estimated by Lee and Kim (2000) and Kim and Lee (2001). In these results, the IT capital stock is defined as 'the assets which are production, process and service itself related to managing, transferring, and reveling information, having the capability of creating the value added and production'. In this definition, not only the traditional electronic communication, such as data communication and related industries, computer and related industries, broadcasting, and contents industries, but also the electronic processing business related to detecting, measuring, recording, and controlling physical phenomena can be incorporated.

In Table 1, we suggest using 8 groups of industries in which manufacturing industry are subcategorized into 9 sub-groups totaling 17 industries. The time period covers 15 years from 1985 to 1999. We deflated IT capital stocks with the producer price index (PPI) and their relative weights which are reported in the Annual Economic Statistics Reports of the Bank of Korea[3].

Table 1. Classification of Total Industry and Manufacturing Industry.

Total Industries		Manufacturing Industries	
Code	**Name**	**code**	**Name**
S1	Mining & Quarrying	M1	Food, Beverage & Tobacco
S2(M)	Manufacturing	M2	Textiles & Leather
S3	Electricity, Gas & Water	M3	Wood, Paper, Publishing & Printing
S4	Construction	M4	Petroleum, Coal & Chemicals

[3] Please consult Kim and Lee (2001) for more detailed estimation of IT capital stock.

S5	Wholesale & Retail Trade, Restaurant, & Hotels	M5	Non-metallic Minerals & Products
S6	Transport, Storage & Communication	M6	Metal, Fabricated Metal Products
S7	Financing, Insurance, Real Estate & Business Service	M7	Machinery & Equipment
S8	Community, Social & Personal Service	M8	Transport Equipment
		M9	Other Manufacturing Industries

2. R&D Capital Stock and Input/Output data

The variables of R&D, value added, labor, and capital are from Lee and Kim (2000) and Seo (2001). As R&D stock is similar to capital stock in its concept, the method of measuring it is also similar by accumulating yearly R&D investment. We use the R&D investment data from the report, 'The Research Report on the R&D Activities of Science and Technology' by Ministry of Science and Technology. As deflators, we use producer price index (PPI) for other ordinary expenditures, Index of Machinery for Equipment Investment (IME) for machinery and equipment, Consumer Price Index (CPI) for labor cost, and Index for Non-Residential Building (INR) for real estate and building. We use real and current data from national accounts for Gross Domestic Product (GDP) of 8 gross-industry group. The amount of labor input is total annual working hours measured by multiplying the number of worker and annual working hours. The results are from Pyo (1998) in the case of capital data. As Pyo (1998) reports only the data covers until 1996, we extend it with perpetual inventory method to 1999.

3. Classification of R&D and IT Intensive and Non-IT-Intensive Industries

To confirm the existence of industry-specific differences in analyzing the role of IT and R&D investment, we first group total industry into some of the characterized groups. Principally, we classify industries by the level of knowledge-using and information-using into the R&D-intensive industries and non-R&D-intensive industries, and the IT-intensive industries and non-IT-intensive industries, respectively. Based on this classification, we estimate the effects of increases in IT or R&D capital stock on productivity.

To classify industries by their capital intensity, we define intensity as the amount of IT and R&D capital stock relative to the value added of total industries in the year of 1998 which is the last year of our estimated capital data. If the intensity of a specific industry is higher than the average intensity of total intensity, we define it as and intensive industry and vice versa.

In addition, we also include the classification of manufacturing and non-manufacturing industries in order to verify how significantly IT and R&D contribute to the performance of manufacturing industries. The classification is as follows:

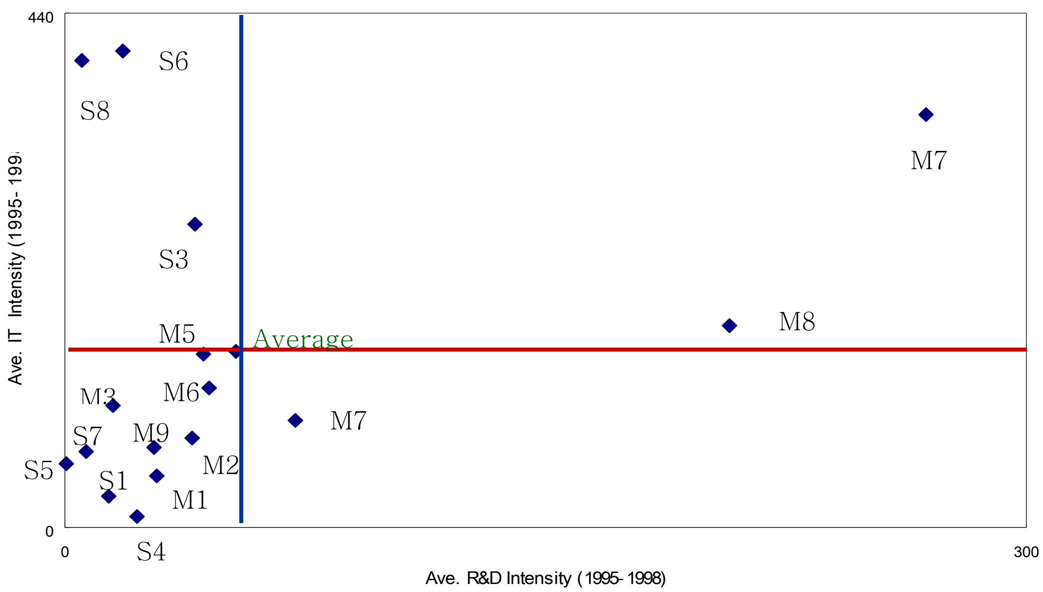

Figure 1. The classification of industries by IT and R&D intensity.

We can find four distinctiveness from figure 1 above. First, technological factors seems to be not significant for non-IT-intensive and non-R&D-intensive industries, such as S1 (Mining & Quarrying), S4 (Construction), S5 (Wholesale & Retail Trade, Restaurant, & Hotels), S7 (Financing, Insurance, Real Estate & Business Service), M1 (Food, Beverage & Tobacco), M2 (Textiles & Leather), M3 (Wood, Paper, Publishing & Printing), M6 (Non-metallic Minerals & Products), M9 (Other Manufacturing Industries) as can be expected. Second, basic service industries with utilities have high intensity of IT capital with low intensity of R&D capital, such as S3 (Electricity, Gas & Water), S6 (Transport, Storage & Communication), S8 (Community, Social & Personal Service). Information processing equipment are seems to be indispensable for these industries because of their idiosyncratic production processes. M7 (Machinery & Equipment) and M8 (Transport Equipment) have both high intensity of IT and R&D capital stock. M7 (Machinery & Equipment) and M8 (Transport Equipment) are the industries closely related with high-tech products in which the information technology and R&D activities are essential. Lastly, M4 (Petroleum, Coal & Chemicals) is the representative industry with high-intensive R&D and low-intensive IT which depends on mass production to achieve economy of scale.

V. The Role of IT and R&D in Industrial Productivity Growth

1. Summary Statistics

Table 2 reports summary statistics:

Table 2. Mean value of major variables

	Pooled Sample	IT-Intensive	Non-IT-Intensive	R&D Intensive	Non-RD-Intensive	Manuf.	Non-Manuf.
Y/L	15.676	18.958	13.706	16.827	15.929	12.908	19.234
K/L	32.205	50.893	20.992	26.939	33.960	20.523	47.224
RD	9290	6046	2884	7106	2185	8110	1180
IT	20572	10853	9719	5942	14630	7857	12715

The IT stock is larger than the RD stock by about two times in the pooled sample. This figure comes from the fact that Korea has concentrated on IT investment in order to become IT leading country, followed the strategy by the Government. On the other hand, the IT-intensive industries and the non-manufacturing industries enjoy high per capita capital stock, since they include utilities such as electricity, gas, and water industry. In addition, we find that the difference in the IT capital stock between groups of industries becomes larger when they are classified by their IT intensity rather than by their R&D intensity. This is because most of the service industries, which employ large amounts of the IT capital stock, are included in the non-R&D-intensive industry, implying that the service sector is relatively more important in the knowledge-based society. The importance of the service sector can also be inferred from the fact that the IT capital stock in the non-manufacturing industry is larger than that of the manufacturing industry in which major service industries are included. The R&D stock of the manufacturing industry is eight times larger than that of the non-manufacturing industry, which implies that the transformation of the manufacturing industry into the knowledge-based industry depends mainly on R&D rather than IT. Therefore, we suggest that the knowledge-intensification and information-intensification of manufacturing and non-manufacturing industries depends on different sources of knowledge-intensification and information-intensification, which is R&D and IT, respectively.

2. Specification Test

In our panel data analysis, we perform the specification test devised by Hausman (1978) in order to choose between fixed- and random effects models[4]. The Hausman test tests for orthogonality of the random effects (v_i) and the regressors. Under the null hypothesis of no correlation between the random effects and the regressors, Hausman statistics have Chi (χ_i) distribution. It is based on the idea that under the hypothesis of no correlation, both OLS in the LSDV and GLS are consistent, but OLS is inefficient, whereas under the alternative hypothesis, OLS is consistent, but GLS is not. Therefore, the random effects model is preferred when the null hypothesis is rejected. Table 3 reports test statistics and the probability of hypothesis rejection for the classified data.

Table 3. Hypothesis test regarding the specification of orthogonality

Sample	Hausman test for Random vs. Fixed effects	
	χ^2	p-value
Pooled Sample	1.357	0.716
IT-intensive	42.432	0.000
Non-IT intensive	3.634	0.304
R&D-intensive	7.064	0.070
Non-R&D intensive	0.621	0.892
Manufacturing	4.370	0.224
Non-Manufacturing	8.443	0.038

Based on the above results, most of the test statistics do not allow one to reject the hypothesis preferring the random effect model (GLS) except for the IT-intensive industries and non-manufacturing industries, for which the fixed effects model (OLS) is preferable.

3. The analysis of IT and R&D's role in industrial productivity

Table 4 demonstrates the results of our panel data analysis for the pooled sample. Both coefficients γ_{RD} and γ_{IT} are statistically significant. However, γ_{IT} is larger than γ_{RD}, implying that the effect of IT on knowledge-intensification and information-intensification is greater than that of R&D ($1.155^{**}>0.122^{**}$).

[4] See Hausman (1878), Grene (2000, p576)

Table 4. Estimates for the pooled sample panel data

Pooled Sample (n=224)	Random effects (GLS)
$\gamma_{K?L}$	0.033 (15.026**)
γ_{RD}	0.122 (5.838**)
γ_{IT}	1.155 (7.974**)
$\overline{R}^2$	0.798

Note) ** and * indicate significant at 1% and 5%, respectively.
t-values are presented in the parenthesis under the estimates.

The above results are similar to those of Brynjolfsson and Hitt (1998) and Lucas (1999) for the firm-level analysis and can be used for supporting the Korean policy of recent strategic investment in IT.

Table 5 reports the estimation results for the IT-intensive and non-IT-intensive industries. In case of the IT-intensive industries, the fixed effect model is preferred in contrast to the random effects model for the non-IT-intensive industries. Our results suggest that R&D has a positive and significant effect on both IT-intensive and non-IT-intensive industries (0.062 for IT-intensive industry and 0.105 for non-IT-intensive industry). However, IT has a positive and significant effect only on the IT-intensive industries (0.097), which is in line with the results of Jorgenson and Stiroh (2000) and Oliner and Sichel (2000), and Stiroh (2001). Therefore, we suggest that the IT investment into the non-IT-intensive industry should be strategically reconsidered in order to increase national economic returns. However, we should carefully interpret the result in deriving policy implications because the output of service industries, the amount of which takes large portion of non-IT-industry, is hard to be measure.

Table 5. Estimates for the IT-intensive and Non-IT-intensive industry

	IT-intensive industry (n=84)	Non-IT-intensive industry (n=140)
	Fixed effects (OLS)	Random effects (GLS)
$\gamma_{K?L}$	0.330 (6.829)**	0.582 (11.215)**
γ_{RD}	0.062 (2.544)**	0.105 (3.613)**
γ_{IT}	0.097 (5.405)**	-0.037 (-1.521)
$\overline{R}^2$	0.997	0.679

Note) ** and * indicate significant at 1% and 5%, respectively.
t-values are presented in the parenthesis under the estimates.

Table 6 reports estimation results of the random effects model for R&D-intensive and non-R&D-intensive industries. The evidence of productivity growth by R&D investment can only be found for the non-R&D intensive industry. Therefore, we infer from this result that Petroleum, Coal and Chemicals industry, Non-metallic Mineral and Products industry, Machinery and Equipment industry, and Transport Equipment industry, which comprise R&D-intensive industries, have low efficiency in R&D investment.

Table 6. Estimates for the R&D-intensive and Non-R&D-intensive industry

	R&D-intensive industry (n=56)	Non-R&D-intensive industry (n=168)
	Random effects (GLS)	Random effects (GLS)
$\gamma_{K?L}$	0.472 (6.678)**	0.488 (13.242)**
γ_{RD}	0.134 (1.869)	0.130 (6.009)**
γ_{IT}	0.049 (1.042)	-0.005 (-0.346)
$\overline{R}^2$	0.846	0.815

Note) ** and * indicate significant at 1% and 5%, respectively.
t-values are presented in the parenthesis under the estimates.

IT investment has no significant effect on both R&D intensive and non-R&D intensive industries. Based on the above results, we imply that the role of knowledge-intensification and informationization by IT in productivity growth was not significant except for the IT-intensive industries in Korea. In addition, it seems that the roles of IT and R&D in productivity enhancement were not complementary to each other.

We can find the estimation result for the manufacturing and non-manufacturing industries in Table 7.

Table 7. Estimates for the manufacturing and non-manufacturing industries

	manufacturing industry (n=126)	Non-manufacturing industry (n=98)
	Random effects (GLS)	Random effects (GLS)
$\gamma_{K?L}$	0.320 (6.383)**	0.895 (17.383)**
γ_{RD}	0.217 (4.902)**	-0.013 (-0.535)
γ_{IT}	0.028 (1.206)	0.035 (2.342)*
$\overline{R}^2$	0.732	0.996

Note) ** and * indicate significant at 1% and 5%, respectively.
t-values are presented in the parenthesis under the estimates.

As a result of the Hausman test, the random effects model is preferred for manufacturing and the fixed effects model is preferred for the non-manufacturing industries. From the significant and positive effect of R&D investment on manufacturing industries (0.217), it seems that manufacturing industry enhances its productivity growth by R&D activities. However, there is no significant effect of R&D investment on non-manufacturing industries. In the case of non-manufacturing industries, only IT has a significant effect on the productivity growth. This result shows the distinct feature of non-manufacturing industry, the large portion of which consists of the service industries, enhancing its productivity growth by informationization**.**

Lastly, we report the estimation results of a between-industry regression in order to analyze the long-term relationships between IT and R&D, and the productivity growth. From table 8, there seems to be no significant relationship between IT and R&D, and productivity growth. From the result, we can infer that IT and R&D investment will have no significant effect on productivity growth of an industry whether it is an IT- or R&D-intensive industry. This last result casts doubt on the significance of the role of IT and R&D to the long-term productivity growth.

Table 8. Estimates of the regression on means (between industries estimates)

	Pooled sample	IT-intensive	Non-IT-intensive	Non-R&D-intensive[a)]	Manuf.	Non-manuf.
$\gamma_{K?L}$	0.647	0.581	0.363	0.592	0.581	0.593
	(4.129)**	(8.415)*	(0.218)	(2.915)**	(2.230)	(1.969)
γ_{RD}	0.094	0.122	0.027	0.140	0.041	0.282
	(1.210)	(3.904)	(0.269)	(1.250)	(0.310)	(1.415)
γ_{IT}	-0.129	0.196	0.141	-0.103	0.063	-0.401
	(-0.652)	(2.003)	(0.499)	(-0.436)	(0.317)	(-0.945)
$\bar{R}^2$	0.809	0.997	0.507	0.753	0.767	0.879

Note) ** and * indicate significant at 1% and 5%, respectively.
t-values are presented in the parenthesis under the estimates.
a) The number of observation for between–industry regression for the case of R&D-intensive industry is too small for meaningful estimation, so that it has not been tried *a priori*.

VI. Conclusions

The rapid process of innovation in the area Information and Communication Technology (IT) was found to be one of the major driving forces that drive productivity growth in the U.S. However, the analysis has been restricted to the case of U.S. because of the difficulties in obtaining the estimates for the IT capital stock. Therefore, in the case of Korea, which is one of the world's leading countries in terms of the IT industry development, the empirical analysis of IT's effect on productivity growth has not yet been fully explored.

In this study, we analyze the effect of IT and R&D, which are considered as two independent input factors that are different from the traditional input factors, such as capital and labor, on industrial productivity growth. Methodologically, we applied both the random effect and the fixed effect model using Hausman (1978) test in order to choose between the two in each particular case.

In our empirical analysis, not only the pooled sample including 16 industries, but also the IT-intensive, non-IT-intensive, R&D-intensive, non-R&D-intensive, manufacturing, and non-manufacturing industries are also analyzed. Although both IT and R&D have positive and significant effects on the productivity growth on the total industry, IT appears to play a more significant role. On the other hand, in the case of the industry-specific analysis, we find no strong evidence that IT investment has a significant effect on overall industrial productivity growth until 1999 except for IT intensive industry. From these results, we infer that the effect of IT investment is restricted to the case of IT-intensive industries alone. Therefore, in order to make the effect of IT investment to be produced on the other type of industries, not only the strategic investment but also the organizational modifications are needed in the latter.

In the case of industrial classification based on the R&D intensity, IT has no positive and significant effect on either type of industry, be it an R&D-intensive or non-R&D-intensive industry. However, there are positive and significant effects of IT on the industrial productivity growth when industries are classified based on the IT intensity. These results are another evidence of the restricted effect IT has on the IT-intensive industries. In the case of R&D, it appears to produce positive and significant effects on the industrial productivity growth except for the R&D-intensive industries. Therefore, it seems that the relationships between IT and R&D have not been complementary in their contribution to the industrial productivity growth. It seems that more strategic approach is needed for IT and R&D investment to have synergetic effect on the productivity growth of Korea.

In recent years, the IT investment accelerated globally and Korea has become one of the most IT-intensive countries in the world. Especially at the industry level, IT investment was strategically encouraged in order to gain relative competitiveness as market competition becomes more severe and the scope of markets broadens. Our results suggest that the effect of IT on productivity growth is primarily restricted to the IT-intensive industries. Therefore, it is recommended to diversify the IT investment among industries, modify the organizational structures of industries in order to fully exploit the potential effect of IT. In addition, it is also suggested to have strategic approach in investing IT to acquire mutually supportive relationships with R&D in order to boost the productivity growth in Korea.

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[Appendix A]

Information and Telecommunication Capital Stocks in the Korean Industrial Sectors[5]

unit: 1990-constant billion Korean-Won

	S1	S2(M)	S3	S4	S5	S6	S7	S8	S
1985	22.6	989.2	7.6	403.5	91.8	761.2	180.9	295.5	2752.3
1986	23.9	1207.4	12.4	406.7	122.6	961.3	240.1	389.2	3363.6
1987	25.3	1488.5	20.3	409.9	163.7	1214.0	318.7	512.6	4153.0
1988	26.8	1854.0	33.0	413.1	218.6	1533.1	423.0	675.2	5176.8
1989	28.3	2333.1	53.9	416.4	291.9	1936.2	561.4	889.3	6510.4
1990	30.0	2966.4	87.9	419.7	389.9	2445.2	745.2	1171.2	8255.3
1991	31.7	3809.9	143.4	423.0	520.7	3088.0	989.0	1542.6	10548.2
1992	33.5	4941.4	233.9	426.3	695.4	3899.8	1312.8	2031.8	13574.8
1993	35.5	6469.4	381.5	429.6	928.7	4925.0	1742.4	2676.0	17588.2
1994	37.5	8545.4	622.2	433.0	1240.2	6219.8	2312.7	3524.6	22935.5
1995	39.7	11381.7	1014.9	436.4	1656.3	7854.9	3069.7	4642.2	30095.8
1996	42.0	15276.5	1655.3	439.9	2212.0	9919.9	4074.5	6114.1	39734.1
1997	44.4	20649.3	2699.9	443.3	2954.1	12527.7	5408.0	8052.9	52779.7
1998	46.9	28092.1	4403.7	446.8	3945.1	15821.1	7178.1	10606.4	70540.4
1999	49.7	38441.4	7182.7	450.3	5268.6	19980.4	9527.5	13969.6	94870.3

unit: 1990-constant billion Korean-Won

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M(S2)
1985	50.6	26.2	15.5	153.5	40.4	427.6	120.1	74.9	80.5	989.2
1986	62.3	33.9	21.3	195.2	51.7	482.2	173.5	102.7	84.6	1207.4
1987	76.8	43.9	29.2	248.1	66.0	543.8	250.7	141.0	89.0	1488.5
1988	94.6	56.8	40.2	315.4	84.3	613.3	362.3	193.4	93.6	1854.0
1989	116.6	73.6	55.2	401.0	107.8	691.6	523.6	265.3	98.5	2333.1
1990	143.6	95.3	75.9	509.7	137.7	780.0	756.7	363.9	103.5	2966.4
1991	176.9	123.4	104.2	648.0	175.9	879.6	1093.6	499.3	108.9	3809.9
1992	218.0	159.8	143.2	823.8	224.8	992.0	1580.4	685.0	114.5	4941.4
1993	268.5	206.9	196.8	1047.2	287.2	1118.7	2283.9	939.7	120.5	6469.4
1994	330.8	267.9	270.5	1331.3	367.0	1261.6	3300.5	1289.1	126.7	8545.4
1995	407.5	346.9	371.7	1692.5	468.9	1422.8	4769.6	1768.5	133.2	11381.7
1996	502.1	449.2	510.8	2151.6	599.2	1604.6	6892.8	2426.2	140.1	15276.5
1997	618.5	581.7	701.9	2735.2	765.6	1809.5	9961.0	3328.5	147.4	20649.3
1998	762.0	753.2	964.6	3477.2	978.2	2040.7	14395.0	4566.3	155.0	28092.1
1999	938.8	975.3	1325.5	4420.4	1249.9	2301.4	20802.7	6264.4	163.0	38441.4

[5] * The estimated IT capital stock of Korea is adjusted result of Lee and Kim (2000) and Kim and Lee (2001).