ICT Input Factor's Productivity

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***Abstract*—** The differences and purpose of this study compared with existing studies are as follows. First, the study classified IT capital stock as capital stocks of hardware, IT, CT, and software, and analyzed the effects of each IT capital stock on the gross output. Second, the study periods were set as 1975 to 2005 and 1995 to 2005, and each period was respectively analyzed.

***Keywords*—**ICT, ICT Productivity, Production Function, IT Productivity Paradox

I. Introduction

Along with the development of information technology (IT) and companies' IT investments, the productivity of IT investments is of critical interest. As Solow indicated, IT productivity studies have been conducted for a long time. The paradox of IT productivity here means that IT investment cannot influence labor productivity per person compared with IT investment.

Arguments on this paradox have been ongoing, and empirical studies have also been conducted on the industry, corporation, and country levels. Among these studies, those indicating that IT investment affects productivity are by Brynjolfsson and Hitt (1996), Linchtenberg (1995) and these studies were conducted on the firm and industry level. Typical studies on the country level include those of Dewan and Kreamer (1998, 2000). By contrast, studies by Morrison and Berndt (1991), Barua (1995), and Loveman (1994) find that computers add nothing to the total output, or that the marginal cost of investment in computers outweighs the marginal benefits. The basic research model of these studies becomes the base of a Cobb–Douglas production function, taking the log to make the function linear. By comparing the coefficient of IT capital with that of non-IT capital in the linear model, differences between the two coefficients were identified.

In addition, for the studies conducted until now, the dependent variables have been subdivided into a country's gross domestic product (GDP) level, size of the company, products and services, and IT-related assets, such as IT capital and labor force (which were subdivided into IT labor force and IT outsourcing). Furthermore, individual industries have been subdivided and relevant studies have been conducted, of which results have shown higher productivity in developed countries, large firms, and manufacturing companies. The difference between IT labor quality and the outsourcing level have provided proof that IT capital has positively impacted productivity (Kim et al., 2007; Dewan and Kreamer, 2000; Tambe and Hitt, 2012) In addition, a study reported that the improvement of total factors productivity and IT capital investment impacts companies' innovative productivity (Park et al., 2007; Kleis et al., 2012).

However, most studies have been conducted on the industry level, and those on the country level are insufficient. Therefore, a better subdivided research model is required for a country-level study.

The differences and purpose of this study compared with existing studies are as follows. First, the study classified IT capital stock as capital stocks of hardware, IT, CT, and software, and analyzed the effects of each IT capital stock on the gross output. Second, the study periods were set as 1975 to 2005 and 1995 to 2005, and each period was respectively analyzed.

This study first attempts to identify whether IT capital and IT labor affect productivity. The remainder of the study is composed as follows. Chapter II provides the research model and hypotheses. Chapter III shows the data and variables. Chapter IV presents the results, and Chapter V offers a conclusion.

II. Research Model

2.2 Research Model

In this study, based on the Cobb–Douglas production function previously mentioned, the effects of individual inputs on gross output are analyzed by classifying the input factors into IT capital, communication technology (CT) capital, software capital, non-ICT capital, IT labor, and non-IT labor. Although studies have been conducted on the effects of gross output on the country and corporate levels, this study was conducted to identify the effects on gross national product and gross output in ICT and non-ICT industries. This can be shown using the following equation.

The production function that is used for a country-level analysis is $Q_{it} = F(IT_{it}, CT_{it}, Soft_{it}, NIT_{it}, L_{it}, L_{nit}, i, t)$, where the country is i = 1, 2, …, N in Year t = 1, 2, …, T, and Q_{it} is annual gross output. The input factors are IT capital stock (IT_{it}, CT_{it}, $Soft_{it}$), non-IT capital stock (NIT_{it}), and labor in an IT economy (L_{it}) and in a non-IT economy (L_{nit}). The dataset includes panel data for 15 countries over the period 1975 to 2005 (N = 15, T = 10).

In order to obtain the elasticity after acquiring the coefficients from the production function, the function should be transformed into a linear equation, which can be

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transformed into the following linear regression equation by taking the logs on both sides.

$$\log Q = \alpha + \beta_{it}\log IT_{it} + \beta_{ct}\log CT_{it} + \beta_{soft}\log Soft_{it} + \beta_{nit}\log NIT_{it} + \beta_{l}\log L_{it} + \mu_i + e_{it} \quad (1)$$

Where μ_i is a country-specific effect invariant over time and is the random error term in the equation, representing the net influence of all unmeasured factors.

This is a base equation indicating that gross national product in a country is made up of its dependent variables. Based on the identical types of equations, industries are grouped into IT and non-IT industries. Input factors that are inputted for individual industries are also grouped into IT and non-IT capital as well as IT and non-IT labor; subsequently, the new model is created.

The coefficients to be determined in this study are β_{it}, β_{ct}, β_{soft}, β_{nit}, and β_{l}. For example, the output elasticity of IT capital is β_{it}, which can be interpreted as the average annual gross output increase if IT capital increases 1%. Other variables can be similarly interpreted.

2.3 Hypotheses

2.1.1 Impact of IT capital classification on national gross output and gross output per industry

Thus far, studies on IT productivity paradox at the country level have been conducted with an emphasis on the impact of IT capital on the GDP growth of a particular country (Dewan and Kreamer, 1998, 2000). In addition, IT capital has not been segmented, and most studies have been on a comparison analysis with non-IT capital. In Kim et al. (2007), IT capital has been sub-divided into hardware capital and software capital; thus, the impact on GDP was studied. Such an approach has also been applied to the IT productivity paradox at the industry level (Brynjolfsson and Hitt, 1996, 1998).

However, IT capital is sub-divided into hardware and software, and is further segmented as IT and CT in accordance with the enhancement of the IT industry and various demands. Regarding the software required to execute this division, the industry is sub-divided into the software development and service industries to stabilize systems and software to comply with business processes. In this study, hardware has been sub-divided into IT and CT, and software has been limited to the areas that excluded service. Thus, IT capital generally displays a growth tendency for the software industry following the development of hardware (Kim et al., 2007). Therefore, each IT input may affect national gross output differently. Based on such existing studies, the following hypotheses are proposed.

H1a: IT capital positively impacts total gross output.
H1b: CT capital positively impacts total gross output.
H1c: Software capital positively impacts total gross output.

III. DATA AND VARIABLES

3.1 Data and Variables

Data used in this study are from the EU KLEMS March 2008 data. Industries are classified according to ISIC ver. 3, and data from a total of 28 OECD and EU countries are provided.

EU KLEMS data provide useful materials for productivity analysis between countries by providing basic data, additional data, capital data, and labor data. In basic data, gross output, value added output, employment, hours of employment, price index, and volume index (1995=100) are provided and can be transformed into constant 1995 US dollars. In addition, this dataset provides subdivided data, including ICT combined with IT, CT, soft, and non-ICT, whereas these data should be excluded based on the ISIC ver. 3 industry classifications. As suggested in the research model, industries can be classified as IT and non-IT industries, and the input variables can also be classified using that method.

The gross output from the table was converted into constant 1995 US dollars in consideration of purchasing power parity by dividing the gross output by the price indices of 1995. All of the remaining variables were provided in constant 1995 US dollars.

TABLE I
EXPLANATION OF VARIABLES

Variables	**Explanation**
Dependent Variable	
Gross Output	Gross output at current basic prices divided by gross output and price indices, where 1995 prices = the base price of 100
Independent Variables	
Economy-wide	
IT	Economy-wide IT (hardware capital stock)
CT	Economy-wide CT (hardware capital stock)
Soft	Economy-wide Soft (software capital stock)
NICT	Economy-wide, with the exception of IT capital stock
Lit	Quantity of labor in the IT economy
Lnit	Quantity of labor in the non-IT economy

Table I shows the summarized technological statistics as major variables of this study. The first table shows the average value of the 14 countries for the 35 years from 1970 to 2005, and the next table shows the average value of the 15 countries for the 10 years from 1995 to 2005. In addition, the industry is classified into the whole industry, the IT economy, and the non-IT economy. All values in the table are in constant 1995 international dollars in consideration with purchasing power parities.

The annual GDP per capita for average labor economy-wide from the summarized statistics for the 35 years starting from 1970 was found to be 42.1 million international dollars, and CT was found to have the highest value among the three IT capital factors with 59.8 million international dollars per capita. Regarding the IT economy, the gross output per capita for labor was 96.3 million international dollars, which was twice the entire industry. CT capital was 573.38 million international dollars per capita for labor, which was 10 times higher than the entire industry average value. In addition, it accounted for approximately 12% of the entire capital. Moreover, all IT capital amounts were found to be higher than the entire industry average. Concerning the non-IT economy, the total gross output per capita for labor was 157.9 million international dollars, and the capital per capita for labor was found to be similar to the entire industry.

From the values for the 10 years from 1995 to 2005, all the values possibly improved compared with the average values for

35 years, as previously mentioned. In particular, the gross output per capita for labor in the IT economy was 219.9 million international dollars, which was twice the average value for 35 years. The values of the IT capital amounts were found to be twice both hardware and software, and it was possible to verify that they were improved similarly economy-wide as well. By contrast, it was found that the degree of improvement for non-IT capital was less than that of IT capital.

Comparing the degree of improvement of IT capital accumulation with the gross output per capita for labor, the IT economy is expected to improve the labor production because of the improvement of IT capital accumulation. In addition, it is believed that the reason why the IT economy has been found to be salient is because of the experience effect of the IT industry itself mentioned in existing research results. The impact of each IT capital on the gross output is examined more concretely in the following analysis.

IV. Results

4.1 An estimation of the production function in accordance with economic unit classifications

4.1.1 Specification tests for 1975 to 2005

Table II shows the results of the specification test regarding the research model from 1975 to 2005 that were proposed in this study.

The first row provides the Hausman test, which makes it possible to avoid inconsistency by testing whether a variable is an explainable variable of orthogonality of the country-specific error component ui. The null hypothesis of the Hausman test is a zero correlation between ui and the regressors and is noted as chi-squared with K degrees of freedom, where K is the number of regressors. According to the results of the Hausman test, the null hypothesis of orthogonality is rejected for the economy-wide case. Therefore, the fixed effects model is preferred to the random effects model.

The second row of the table provides an F-test to examine the estimated coefficients of the dummy variables of the 12 panel groups, which are included in the model when there are 15 panel groups in total. All research model proposed in this study show $p < 0.01$; thus, the null hypothesis is rejected at the 1% significant level. Therefore, the fixed effects model, which reflects the object characteristics of the panels in the model, is adequate.

The third row presents the result of the Breusch and Pagan Lagrangian multiplier test, which is used to test the statistical significance of country random effects. The null hypothesis is that the variance $\sigma^2_{u_i}$ of the country specific error component u_i is equal to 0; thus, all research model reject the null hypothesis at the 1% significant level. Therefore, the random effects model is preferred to a pooled OLS estimation.

In the fourth row, a Wooldridge test is used to test whether the error term eit has autocorrelation within a panel group. The test results showed that the null hypothesis was not a first-order autocorrelation, and that all research model rejected the null hypothesis at the 1% significant level. Therefore, first-order autocorrelation existed.

TABLE II
HYPOTHESIS TESTS ON THE PRODUCTION REGRESSION SPECIFICATIONS FROM 1975 TO 2005

1975to2005	Economywide
Hausman test (Ho: difference in coefficients not systematic)	chi2(6) = 103.25
	Prob>chi2 = 0.0000
F test that all u_i=0:	F(12, 286) =248.28
	Prob > F = 0.0000
Breusch and Pagan Lagrangian multiplier test for random effects(Var(u) = 0)	chi2(1) =869.70
	Prob > chi2 =0.0000
Wooldridge test for autocorrelation in panel data(H0: no first-order autocorrelation)	F(1, 12) =96.553
	Prob > F = 0.0000

4.1.2 IT capital returns structure from 1975 to 2005

Previously, it was confirmed that first-order autocorrelation existed using the Wooldridge test, presented in the table. Therefore, this paper estimates an autoregression (AR; 1) model that allows for heteroskedasticity and contemporaneous correlation between cross-sections in addition to first-order autoregression. Moreover, the table findings are explained based on a fixed effects model in accordance with the result of the Huasman test.

The analysis shows that the explanation power of the sum of IT, CT, software, non-IT capital, IT labor, and non-IT labor, which are the components of IT capital, was found to be 91.6% (R2). Regarding variables that have a significant statistical impact on the gross output of the economy, IT and CT, which represent the hardware variables of the various IT capital values, were found to be positive and significant (IT: $p < 0.01$; CT: $p < 0.05$). However, software capital and IT labor did not have a significant effect on the gross output.

The IT elasticity was 0.055. An increase in the IT capital stock of 1% increases average gross output by 0.055%. The elasticity of CT, IT capital, and non-IT labor were 0.043, 0.214, and 0.616, respectively. Therefore, hardware capital stock has increased average gross output from 1975 to 2005(table 3).

Based on the results, it was possible to confirm that IT hardware has been contributing to the development of economic gross output for the past 30 years.

Table IV presents the results of the detailed verification of the effects of IT capital stock, non-IT capital stock, and labor on the gross output from 1995 to 2005.

For the first term, if the null hypothesis is rejected by the Hausman test, the fixed-effects model is preferred.

The second term is the F verification term used to determine whether the estimated coefficients of the dummy variables in each panel group are 0. Therefore, a fixed-effects model that considers the object properties of the panel in the model is more appropriate than pooled OLS is.

TABLE III
PRODUCTION FUNCTION ESTIMATES FROM 1975 TO 2005 BASED ON THE FIXED AND RANDOM EFFECTS MODELS (AR (1) MODEL)

	Fixed Effect	Random Effect
	Economywide	Economywide
	coef/se	coef/se
kit_o	0.055***	0.025**
	(0.012)	(0.010)
kct_o	0.043*	-0.001
	(0.025)	(0.018)
ksoft_o	0.015	-0.004
	(0.019)	(0.014)
knit_o	0.214***	0.760***
	(0.052)	(0.034)
l_it	-0.016	0.085**
	(0.036)	(0.035)
l_nit	0.616***	0.294***
	(0.087)	(0.055)
_cons	-0.208***	-2.223***
	(0.005)	(0.165)
DF	273	305
R^2	0.916	0.926
note: *** p<0.01, ** p<0.05, * p<0.1		

4.1.3 Specification tests for 1995 to 2005

The null hypothesis of the third term is that the variance $\sigma^2_{u_i}$ of the country-specific error component u_i is equal to 0. Because Economywide reject the null hypothesis at the 1% significance level, the random-effects model is preferred to a pooled OLS estimation.

The fourth term is a Wooldridge test that aims to test whether the error term eit has autocorrelation in a panel group; the results show that autocorrelation exists for Economywide.

Because first-order autocorrelation exists, this paper estimates whether an AR (1) model allows for heteroskedasticity and contemporaneous correlation between cross-sections in addition to first-order autoregression. Moreover, the error term ui is interpreted using the results of a fixed effects model that regards the error term ui as fixed effects; this is in accordance with the features of national panel data that are used in the previous three tests and in this study.

TABLE IV
HYPOTHESIS TESTS REGARDING THE SPECIFICATION OF THE PRODUCTION REGRESSIONS FROM 1995 TO 2005

	Economywide
Hausman test(Test: Ho: difference in coefficients not systematic)	chi2(6) = 70.80
	Prob>chi2 = 0.0000
F test that all u_i=0:	F(12, 116) = 463.71
	Prob > F = 0.0000
Breusch and Pagan Lagrangian multiplier test for random effects(Var(u) = 0)	chi2(1) = 269.79
	Prob > chi2=0.0000
Wooldridge test for autocorrelation in panel data(H0: no first-order autocorrelation)	F(1, 12) =59.880
	Prob > F = 0.0000

4.1.4IT capital returns structure from 1995 to 2005

As a result of the analysis, the explanation power of the components of IT capital such as IT, CT, Soft, non-IT capital, IT labor, and non-IT labor economy-wide during the 10 years from 1995 to 2005 was found to be R2 = 99%. For the variables that had a statistically significant impact on the total economic production, the hardware variables of IT capital such as IT, CT, and IT labor were found to be positive and significant (IT: $p < 0.1$, CT & Lit: $p < 0.01$)(table 5). However, it was found that software capital and non-IT labor did not have a significant impact on the gross output. Such results implied that the IT hardware industry is still affecting the gross output. By contrast, IT labor did not affect the gross output in the past 30 years; however, it has been significantly affecting the gross output in the past 10 years. Such a result may be due to the contribution to productivity by knowledge workers. In other words, in the past, development was based on the manufacturing industry; however, a transition to an economic structure where the knowledge service and manufacturing industries have been affecting total economic production occurred after 1995.

TABLE V
PRODUCTION FUNCTION ESTIMATES BASED ON THE FIXED AND RANDOM EFFECTS MODELS FROM 1995 TO 2005 [AR (1) MODEL]

1995_2005_AR(1)	Fixed Effect	Random Effect
	Economywide	Economywide
	coef/se	coef/se
kit_o	0.036*	0.030
	(0.023)	(0.012)
kct_o	0.104***	0.072*
	(0.043)	(0.023)
ksoft_o	-0.002***	-0.030***
	(0.023)	(0.018)
knit_o	0.701***	0.838***
	(0.066)	(0.030)
l_it	0.150***	0.135***
	(0.046)	(0.047)
l_nit	-0.310***	-0.010***
	(0.096)	(0.057)
_cons	-0.023**	-1.815***
	(0.007)	(0.130)
DF	103	135
R^2	0.99	0.902
note: *** p < 0.01, ** p < 0.05, * p < 0.1		

V.CONCLUSIONS

This study is concerned with the IT productivity paradox at the country level; thus, it analyzed data of 15 countries from the past 30 years obtained from EU KLEMS. Existing studies regarding the IT productivity paradox at the country level classified only IT capital stock and non-IT capital stock, and the analysis was conducted by classifying the entire subject country or on the basis developed countries and developing countries (Dewan and Kreamer, 1998, 2000; Kim et al., 2007).

The differences and purpose of this study compared with existing studies are as follows. First, the study classified IT capital stock as capital stocks of hardware, IT, CT, and software, and analyzed the effects of each IT capital stock on the gross output. Second, the study periods were set as 1975 to 2005 and 1995 to 2005, and each period was respectively analyzed. In this manner, the study determined the change of the effects of each IT capital stock, and it analyzed the spillover effects of IT capital stock based on the IT capital stock, economy level, and fragmentation of the study period unlike the existing studies.

As a result of the analysis, the effects of each IT capital stock per economy level for the 30 years from 1975 to 2005 are as follows. IT capital stock was found to have a significant impact on the gross output in country levels

Economy-wide, only IT and CT in the area of hardware were found to have a significant impact on the gross output. In particular, a significant result of IT labor affecting the gross output of the entire economy was not found. On average, only hardware had been affecting the gross output of the entire economy during the 30-year period, and software and IT labor did not have a significant impact. This may be due to the rapid propagation of office automated devices and computer devices since the mid-1970s and the growth of information communication devices since then.

The impact of each IT capital stock on the economy levels during the 10 years from 1995 to 2005 are as follows. Compared with the previous analysis results of the 30-year period mentioned previously, the impact of IT and non-IT labor of IT capital stocks on the gross output of each economy had been weakened or eliminated. The results of this study indicate that the IT productivity paradox does not exist, and that the effects on each economy are different depending on the type, economy level, and period of each IT capital stock. This study used data of 15 OECD countries for analysis, thus producing results for countries where the accumulation and use of IT infrastructure are relatively well-conducted. Hence, such results may be used for a national development strategy through the implementation and use of IT capital stock for countries where IT infrastructure is insufficient.

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