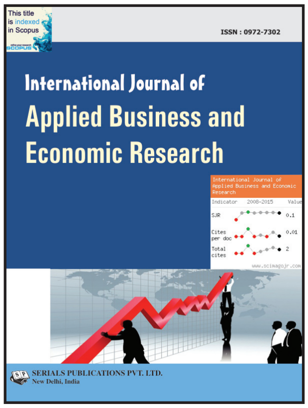

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IT Productivity Paradox at the Country Level

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ABSTRACT

This study investigates the Information Technology (IT) productivity paradox at the country level using EU KLEMS data for 15 countries, divided into two periods, 1975 to 2005 and 1995 to 2005. The economic units of each country are divided into IT and non-IT capital, IT and non-IT labor, and subdivided further into economic units. IT capital stock was found to have a significant impact on the gross output in all three levels of the economy: economy-wide, IT economy, and non-IT economy. In the case of the IT economy, all IT capital stock such as IT, CT, and Soft were found to have a statistically significant impact. In the case of the non-IT economy, only IT in the area of hardware significantly affected gross output. 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 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 types, economy level, and period of each IT capital stock.

***Keywords*:** IT productivity paradox, IT Economy, KLEM data, ICT Capital, IT infrastructure.

1. 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, studies on IT productivity have been conducted for a long time. The paradox of IT productivity means that IT investment cannot influence labor productivity per person when compared with IT investment.

Arguments regarding this paradox are ongoing, and empirical studies have been conducted at the industry, corporation, and country levels. Among these studies, those indicating that IT investment affects productivity on the firm and industry level are by Brynjolfsson and Hitt (1996), Linchtenberg (1995). Typical studies on the country level include those of Dewan & Kreamer (1998, 2000). By contrast, studies by Morrison & 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. Differences between the two coefficients were identified by comparing the coefficient of IT capital with that of non-IT capital in the linear model.

In prior studies, 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. Furthermore, individual industries have been subdivided and relevant studies have been conducted showing higher productivity in developed countries, large firms, and manufacturing companies. The differences between IT labor quality and the level of outsourcing are proof that IT capital has positively impacted productivity (Dewan & Kraemer, 2000, Kim et. al., 2008, Tambe & Hitt, 2012). In addition, studies have reported that the improvement in total factor productivity and IT capital investment impacts innovative productivity of companies (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. An improved subdivided research model is required for a country-level study. To investigate the IT productivity paradox at the country level, this study classifies the economic units of the country into three segments and dividing the input factors into IT and non-IT capital, and IT and non-IT labor, and by subdividing the factors into economic units. Subdivided economic units are classified as gross national product and gross output in the information and communications technology (ICT) economy and in the non-ICT economy, and each input factor is divided into the individual economic units' input factors.

The remainder of the study is composed as follows. Section 3 and 4 provide the research model and hypotheses. Section 5 shows the data and variables. Section 6 presents the results. Section 7 offers a conclusion.

2. PRODUCTION FUNCTION FRAMEWORK

Studies on the productivity paradox measure the input coefficients of a Cobbs and Fortune 500 firms by using IT capital and IT employment data as inputs for efficient production, where the production factors that are included in the production process for a certain period are independent variables and the production volume is a dependent variable. The following functions and equations represent the production function.

$$Q = f(K, L) \tag{1}$$

$$Q = A^{N}K^{\beta}L^{1-\beta} \tag{2}$$

Equations (1) and (2) show the production function of the input factors where: Q is gross output, K is capital stock, and L is labor. Most input factors for productivity studies are composed of capital and labor. Because the importance of information and technology is emphasized, studies have been conducted by classifying these into IT capital and non-IT capital, and by obtaining the coefficients of IT capital and comparing them with non-IT capital. Finally, study results of IT productivity were drawn.

The variable r can be obtained by transforming the Cobb-Douglas function into a linear equation such as Equation (2) to be able to segment the inputs into IT capital and non-IT capital; for example, $r = (\alpha_1 + \alpha_2 + \beta)$. The following regression equation can be created by taking the logs of both sides and the rates of return can be calculated using r.

$$\log Q_T = \alpha_1 \log K_{IT} + \beta_1 \log K_{NIT} + \beta_2 \log L_T \quad (3)$$

Therefore, the coefficient values are obtained by grouping capital and labor between IT and non-IT, and by determining the productivity of IT investment. Furthermore, the marginal product can be compared among these input factors.

3. 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. 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 $i = 1, 2, \ldots N$, in Year $t = 1, 2, \ldots T$, 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 transformed into the following linear regression equation by taking the logs on both sides.

$$\log Q = \alpha + \beta_{it} \log IT_{it} + \beta_{ct} \log CT_{it} + \beta_{soft} \log Soft_{it} + \beta_{nit} \log NIT_{it} + \beta_1 \log L_{it} + \mu_i + e_{it} \quad (4)$$

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 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_1. 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.

The linear regression models for the individual IT and non-IT economy are as follows:

$$\log Q_{it} = \alpha + \beta_{it_{it}}) \log IT_{it} + \beta_{ct_{it}} \log CT_{it} + \beta_{soft_{it}} \log soft_{it} + \beta_{nit_{it}} \log Nit_{it} + \beta_{1_{it}} \log L_{it} + \mu_{i_{it}} + \varepsilon_{it_{it}} \quad (5)$$

$$\log Q_{nit} = \alpha + \beta_{it_{nit}} \log IT_{nit} + \beta_{ct_{nit}} \log CT_{nit} + \beta_{soft_{nit}} \log soft_{nit} + \beta_{nit_{nit}} \log Nit_{nit} + \beta_{1_{nit}} \log L_{nit} + \mu_{i_{nit}} + \varepsilon_{it_{nit}} \quad (6)$$

Equations (5) and (6) show the relationship between input factors and products in an IT and a non-IT economy, respectively. Both equations examine the effect on the gross output of individual industries as each input factors increase by 1% by obtaining $\beta_{it_{it}}$, $\beta_{ct_{it}}$, $\beta_{soft_{it}}$, $\beta_{nit_{it}}$, and $\beta_{1_{it}}$; and $\beta_{it_{nit}}$, $\beta_{ct_{nit}}$, $\beta_{soft_{nit}}$, $\beta_{nit_{nit}}$, and $\beta_{1_{nit}}$, respectively.

This study aims to examine whether IT investment affects gross output over time. Therefore, it is imperative to compare such factors as infrastructure, definition of inputs, and production efficiency between countries to conduct the study for several countries. A fixed-effects model and a random-effects model could be used to adjust cross-sectional heterogeneity between countries 4.

In a fixed-effects model, country-specific effects μ_i are represented by dummy variables in the regression, having one for each country in the sample. The fixed-effects model generates a type of within-countries regression by eliminating μ_i, as shown in the following formula. Thus, it can calculate consistency in β by estimating OLS, even though it does not meet cov $(x_{it}, \mu_i) \neq 0$.

$$\log Q_{it} - \log Q_i = \alpha + \beta_{it}(\log IT_{it} - \log IT_i) + \beta_{ct}(\log CT_{it} - \log CT_i) + \beta_{soft}(\log soft_{it} - \log soft_i) + (\log NIT_{it} - \log NIT_i) + \beta_L(\log IT_{it} - \log IT_i) + \varepsilon_{it} - \varepsilon_i \quad (7)$$

In a random-effects specification, country effects are characterized by time in variance by using a time-invariant component μ_i of the composite error term $\omega_{it} = \mu_i + \varepsilon_{it}$. The component μ_i is the random disturbance that characterizes country *i*, and is constant over time. These country-specific error components are assumed to be randomly distributed across the cross-section of countries. In the random effects model, Equation (7) is estimated by using generalized least squares (GLS) to consider the non-spherical error structure under this specification. Such a random effects model has the advantage of avoiding discord estimation, because μ_i is uncorrelated with the regressors; therefore, it is assumed to be strong.

4. HYPOTHESIS

Thus far, studies on the 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 3,4. In addition, IT capital has not been segmented, and most studies utilize a comparison analysis with non-IT capital. In Kim et. al., (2008), IT capital has been sub-divided into hardware capital and software capital; therefore, the impact on GDP was studied 7. Such an approach has also been applied to the IT productivity paradox at the industry level 1.

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 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 7. 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.

H1d: IT labor positively impacts total gross output.

Moreover, not only do IT, CT, and software capital affect national gross output, but they also likely affect each industry differently. Thus, this study aims to examine the impact of IT capital on the gross output of an IT economy and a non-IT economy. In each industry, capital consists only of the corresponding capital for each industry. Therefore, the following hypotheses are proposed.

H2a: IT capital, which is an input in an IT economy, positively affects gross output in an IT economy.

H2b: CT capital, as an input in an IT economy, positively affects gross output in an IT economy.

H2c: Software capital, as an input in an IT economy, positively affects gross output in an IT economy.

H2d: IT labor, as an input in an IT economy, positively affects gross output in an IT economy.

H3a: IT capital, as an input in a non-IT economy, positively affects gross output in a non-IT economy.

H3b: CT capital, as an input in a non-IT economy, positively affects gross output in a non-IT economy.

H3c: Software capital, as an input in a non-IT economy, positively affects gross output in a non-IT economy.

5. DATA AND VARIABLES

Measurement Issues

The variables used in this study are gross output, IT capital, non-IT capital, IT labor, and non-IT labor. Because the analysis is conducted for long periods using individual countries, the analysis should be conducted under conditions that consider exchange rates and inflation rates for individual variables. In addition, regarding IT capital, measurement problems should be sufficiently considered because IT productivity is determined according to the level of the deflator (Brynjolfsson, 1993). Next, characteristics and considerations that are used in a productivity analysis are to be identified.

Common characteristics of all variables used in productivity analysis should consider exchange rates and inflation rates, as previously mentioned. This is transformed into fixed US dollars in a single period by using the deflator.

Gross output is also used individually as value added and gross output. Value added is the value retained after labor compensation and taxes are subtracted from gross output, or GDP. According to Kudyba and Diwan (2002), an analysis using gross revenue and value added as dependent variables are acceptable (Kudyba & Diwan, 2002).

Regarding IT capital, the definition of IT differs among researchers and institutions. The Bureau of Economic Analysis (BEA) defines it as office, computing, and accounting machinery using IT development and CT development. IT, CT, and realized software are also defined as IT capital. Because this definition of IT is diverse and complex, IT technological skills are also diverse; consequently, depreciation should appear differently and the lag should be considered due to the complexity of use. In other words, clearly measuring IT capital is not easy, and the productivity of IT capital may differ depending on who uses it and how it is used.

Under the IT productivity paradox, IT means investment, and the investment is the flow and the subset of IT capital stock. Therefore, Dewan and Kraemer (1998) transformed and analyzed IT capital stock as IT investments during two periods by analyzing the production function with variations from 1992 to 1985. Study results that were compared and analyzed by Kudyba and Diwan (2002) using IT capital stock and IT flow as independent variables in each production function showed that both variables positively influenced gross output 3,13. Total capital stock is generally calculated as the sum of entire investments and determined after considering the depreciation.

Productivity in the IT productivity paradox implies the labor productivity per worker. However, workers are also classified according to workmanship, education levels, and compensation levels. Working hours per person also differ among classifications, industries, or countries. Therefore, measuring the labor force is an important element to consider in addition to IT capital. Dewan and Kraeamer (1998) used the number of workers as the independent variable, and Dewan and Kraeamer (2000) and Han et. al., (2011) set total labor force input hours as an input factor by using the number of workers multiplied by the average number of work hours per year. In the study by Brynjolfsson and Hitt (1996), labor force was also set as labor expenses.

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 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 considering the 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.

Regarding the addition of the existing IT capital stock, capital stock has been studied separately for IT and non-IT industries to examine whether IT investment affected gross output. By contrast, this study examines whether IT capital stock affected the gross output by sub-dividing IT capital stock into hardware and software, and again sub-dividing hardware into IT and CT.

Furthermore, this study investigates how each IT capital stock has affected each industry by conducting the study of sub-dividing the national economy of a country into IT economy and non-IT economy.

Moreover, it will examine the impact of IT capital stock in the IT economy on the total production of the non-IT economy, as it is included in the production function of the non-IT economy as a production element. It will also examine the impact of IT capital stock in the non-IT economy on the gross output of the IT economy, as it is included in the production function of the IT economy as a production element.

Each capital stock, as shown in Table 20.1, is sub-divided into IT capital stock (i.e., IT, CT, Soft) and non-IT capital stock, and is further sub-divided into capital stock within the IT economy and capital stock within the non-IT economy.

Table 20.1
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 capital, with the exception of IT capital stock
Lit	Quantity of labor in the IT economy
Lnit	Quantity of labor in the non-IT economy
IT Economy	
IT_it_o	IT (hardware capital stock) in the IT economy
CT_it_o	CT (hardware capital stock) in the IT economy
Soft_it_o	Soft (software capital stock) in the IT economy
NICT_it_o	All capital except the IT capital stock in the IT economy
Lit	Quantity of labor in the IT economy
Non IT Economy	
IT_nit_o	IT (hardware capital stock) in the non-IT economy
CT_nit_o	CT (hardware capital stock) in the non-IT economy
Soft_nit_o	Soft (software capital stock) in the non-IT economy
NICT_nit_o	All capital except the IT capital stock in the non-IT economy
Lnit	Quantity of labor in the non-IT economy

Table 20.2 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 economy is classified into the whole economy, 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 improved compared with the average values for the 35-year sample. 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 as the previous sample. 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. In 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 increase the labor productivity because of the improvement of IT capital accumulation. In addition, it is assumed that the IT economy is salient 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.

Table 20.2
Summary Statistics for the Full Sample
(Unit: Million $)

	1970 to 2005					
	Economy wide		*IT Economy*		*Non IT Economy*	
	Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
Total Gross Output	945,421.4	2,389,257.5	91,097.4	245,110.8	854,324.0	2,154,563.5
Total Gross Output per Labor	42.1	74.9	96.3	179.3	39.7	70.5
IT Capital per Labor	16.6	50.7	29.7	89.4	16.0	48.9
CT Capital per Labor	59.8	173.0	573.3	1,585.7	36.0	107.2
Soft Capital per Labor	33.1	95.8	76.5	212.0	31.1	90.4
Non IT Capital per Labor	4,907.5	14,135.9	4,163.2	11,798.5	4,938.0	14,232.2
Labor Hour (Millions)	41,855.2	59,550.4	1,690.6	2,650.5	40,058.0	56,877.6
Number of Laborers (Thousands)	22,466.5	31,904.5	946.3	1,367.0	21,520.2	30,551.5

	1995 to 2005					
Unit: Million $	*Economy wide*		*IT Economy*		*Non IT Economy*	
	Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
Total Gross Output	1,492,837.1	3,753,912.6	208,799.7	578,298.3	1,284,037.4	3,208,454.2
Total Gross Output per Labor	58.5	96.4	219.9	402.9	52.3	85.5
IT Capital per Labor	41.2	116.5	70.7	190.7	40.0	113.3
CT Capital per Labor	128.9	370.7	1,204.8	3,219.7	78.3	233.4
Soft Capital per Labor	80.1	232.8	180.8	479.9	75.5	221.0
Non IT Capital per Labor	7,402.2	21,037.3	7,654.4	21,811.3	7,389.9	20,996.9
Labor Hour (Millions)	45,569.0	70,233.0	1,777.2	2,806.9	43,791.7	67,435.6
Number of Laborers (Thousands)	25,524.0	38,944.1	949.6	1,435.4	24,574.5	37,516.9

Note: Dollar figures are in terms of constant 1995 international dollars.

6. RESULTS

Specification tests for 1975 to 2005

Table 20.3 shows the results of the specification test regarding the three economic models from 1975 to 2005 that were proposed in this study.

The first row provides a Hausman test, which make it possible to avoid inconsistency by testing whether a variable is an explainable variable of orthogonality of the country-specific error component μ_i. The null hypothesis of the Hausman test is a zero correlation between μ_i 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, IT economy, and non-IT economy cases. 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 three economic models proposed in this study show $p<0.01$; therefore, 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 three economic models reject the null hypothesis at the 1% significance 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 e_{it} has autocorrelation within a panel group. The test results showed that the null hypothesis was not a first-order autocorrelation, and that all three economic models rejected the null hypothesis at the 1% significance level. Therefore, first-order autocorrelation existed.

Table 20.3
Hypothesis Tests on the Production Regression Specifications from 1975 to 2005

1975 to 2005	*Economy wide*	*IT_Economy*	*Non_IT_Economy*
Hausman test (H0: difference in coefficients not systematic)	chi2(6) = 103.25 Prob > chi2 = 0.0000	chi2(5) = 70.54 Prob > chi2 = 0.0000	chi2(5) = 102.62 Prob > chi2 = 0.0000
F test that all $u_i = 0$:	F(12, 286) = 248.28 Prob > F = 0.0000	F(12, 287) = 36.25 Prob > F = 0.0000	F(12, 287) = 279.26 Prob > F = 0.0000
Breusch and Pagan Lagrangian multiplier test for random effects (Var (u) = 0)	chi2(1) = 869.70 Prob > chi2 = 0.0000	chi2(1) = 497.02 Prob > chi2 = 0.0000	chi2(1) = 841.35 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	F(1, 12) = 151.989 Prob > F = 0.0000	F(1, 12) = 82.819 Prob > F = 0.0000

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 autoregressive 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 Hausman test.

The analysis shows that the explanation power of the sum of IT, CT, software, non-IT capital, IT labor, and non-IT labor that 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.

By contrast, IT, CT, and software, which are the components of IT capital, were found to be positive and significant ($p < 0.01$) to the IT economy, and non-IT capital, IT labor, and non-IT capital were also found to be positive and significant (Lit: $p < 0.01$, Knit_it: $p < 0.05$). Regarding the elasticity point of each IT capital stock, it was found that IT was 0.089, CT was 0.185, and software was 0.077. In addition, non-IT capital stock was 0.180 and IT labor was 0.328.

Lastly, regarding the non-IT economy, only IT, which is the hardware of IT capital variables, was positive and significant at the 1% significance level. CT and software were found to be insignificant. Moreover, non-IT labor and non-IT capital were found to be positive and significant at the 1% significance level. The IT elasticity point was 0.049, and non-IT capital and non-IT labor were 0.264 and 0.622, respectively.

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 20.4
Production Function Estimates from 1975 to 2005 Based on the Fixed and Random Effects Models (AR(1) Model)

	Fixed Effect			*Random Effect*		
	Economy wide	*IT_Economy*	*Non-IT Economy*	*Economy wide*	*IT_Economy*	*Non-IT Economy*
	coef/se	*coef/se*	*coef/se*	*coef/se*	*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	0.328***		0.085**	0.143***	
	(0.036)	(0.085)		(0.035)	(0.046)	

	Fixed Effect			*Random Effect*		
	Economy wide	*IT_Economy*	*Non-IT Economy*	*Economy wide*	*IT_Economy*	*Non-IT Economy*
	coef/se	*coef/se*	*coef/se*	*coef/se*	*coef/se*	*coef/se*
l_nit	0.616***		0.622***	0.294***		0.404***
	(0.087)		(0.070)	(0.055)		(0.042)
kit_it_o		0.089***			0.059***	
		(0.021)			(0.015)	
kct_it_o		0.185***			0.127***	
		(0.049)			(0.032)	
ksoft_it_o		0.077***			0.048**	
		(0.027)			(0.020)	
knit_it_o		0.180**			0.661***	
		(0.077)			(0.039)	
kit_nit_o			0.049***			0.025**
			(0.011)			(0.010)
kct_nit_o			–0.019			–0.018
			(0.021)			(0.016)
ksoft_nit_o			0.005			–0.011
			(0.018)			(0.014)
knit_nit_o			0.264***			0.769***
			(0.048)			(0.034)
_cons	–0.208***	–0.058***	–0.244***	–2.223***	–1.478***	–2.414***
	(0.005)	(0.012)	(0.004)	(0.165)	(0.113)	(0.160)
DF	273	274	274	305	305	305
R^2	0.916	0.540	0.910	0.926	0.913	0.917

Note: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

Specification tests for 1995 to 2005

Table 20.5 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 row, if the null hypothesis is rejected by the Hausman test, the fixed-effects model is preferred. By contrast, if it is accepted, the random-effects model is preferred. Because the chi-squared value of the IT economy was 5.31, the random effects model is preferred. However, the remaining two economic classifications, which were economy-wide and non-IT economy, reject the null hypothesis; thus, a fixed-effects model is preferred for those.

The second row is the F verification term used to determine whether the estimated coefficients of the dummy variables in each panel group are 0. Because the p values of all three economy levels are less than 0.01, the null hypothesis is rejected at the 1% significance level. Therefore, a fixed-effects model that considers the object properties of the panel in the model is more appropriate than pooled OLS.

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 all three economic models reject the null hypothesis at the 1% significance level, the random-effects model is preferred to a pooled OLS estimation.

The fourth row 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 all three economies.

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 μ_i is interpreted using the results of a fixed effects model that regards the error term μ_i 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 20.5
Hypothesis Tests regarding the Specification of the Production Regressions from 1995 to 2005

	Economy wide	*IT_Economy*	*Non_IT_Economy*
Hausman test(Test: Ho: difference in coefficients not systematic)	chi2(6) = 70.80 Prob > chi2 = 0.0000	chi2(5) = 5.31 Prob > chi2 = 0.3795	chi2(5) = 84.24 Prob > chi2 = 0.0000
F test that all u_i = 0:	F(12, 116) = 463.71 Prob > F = 0.0000	F(12, 117) = 48.78 Prob > F = 0.0000	F(12, 117) = 949.40 Prob > F = 0.0000
Breusch and Pagan Lagrangian multiplier test for random effects (Var (u) = 0)	chi2(1) = 269.79 Prob > chi2=0.0000	chi2(1) = 384.02 Prob > chi2=0.0000	chi2(1) = 410.37 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	F(1, 12) =71.772 Prob > F = 0.0000	F(1, 12) =73.678 Prob > F = 0.0000

IT Capital Returns Structure from 1995 to 2005

As a result of the analysis, the explanatory 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 $R^2 = 99\%$. 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: $p < 0.01$). 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, but 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 the past, development was based on the manufacturing industry, but a transition to an economic structure where the knowledge service and manufacturing industries have been affecting total economic production occurred after 1995.

This point is seen more prominently in the case of the IT and non-IT economies. In the case of the IT economy, all IT hardware, software, and labor have significantly impacted the gross output of the IT economy in the past 30 years, while IT has not had an impact since 1995. In addition, in the past 30 years in the non-IT economy, IT, non-IT capital stock, and non-IT labor of IT hardware have contributed to the gross output. However, IT software and non-IT capital stock had contributed to the gross output according to the 1995-2005 analysis.

IT hardware did not have a significant impact on the gross output in the IT economy; however, the contribution of IT software to gross output in the non-IT economy is because the sample countries in this study were 15 OECD countries. These countries reached limitations in terms of the impact of IT hardware capital stock on the national gross output in the mid-1990s, and the accumulation since then did not significantly impact the gross output due to the law of diminishing margins. However, IT software significantly affects the gross output of the non-IT economy because IT hardware capital stock is being used sufficiently as IT infrastructure.

Table 20.6
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*		
	Economy wide	*IT_Economy*	*Non-IT Economy*	*Economy wide*	*IT_Economy*	*Non-IT Economy*
	coef/ se	*coef/ se*	*coef/ se*	*coef/ se*	*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***	0.395***		0.135***	0.052	
	(0.046)	(0.127)		(0.047)	(0.060)	
l_nit	–0.310***		–0.247***	–0.010***		0.170***
	(0.096)		(0.082)	(0.057)		(0.037)
kit_it_o		0.107			0.105***	
		(0.037)			(0.025)	
kct_it_o		0.043***			0.155***	
		(0.092)			(0.056)	
ksoft_it_o		0.067*			0.027*	
		(0.034)			(0.032)	
knit_it_o		0.296***			0.657***	
		(0.091)			(0.053)	
kit_nit_o			–0.015***			0.013
			(0.027)			(0.011)
kct_nit_o			0.122			0.046
			(0.037)			(0.019)
ksoft_nit_o			0.014***			-0.027***
			(0.027)			(0.018)
knit_nit_o			0.745***			0.852***
			(0.065)			(0.033)
_cons	–0.023**	–0.209***	–0.058	–1.815***	–1.409***	–2.108***
	(0.007)	(0.020)	(0.009)	(0.130)	(0.130)	(0.128)
DF	103	104	104	135	135	135
R^2	0.99	0.848	0.99	0.902	0.837	0.878

Note: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

7. CONCLUSTION

This study is concerned with the IT productivity paradox at the country level; therefore, it analyzed the 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 of developed countries and developing countries (Dewan & Kraemer, 1998, 2000, Kim et. al., 2008).

This study differs from previous studies. First, this 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, this study analyzed the entire economy and the differences of the impacts of IT capital stocks on each economy level by sub-dividing the economy into the IT and non-IT economies. Lastly, the study periods were set as 1975 to 2005 and 1995 to 2005, and each period was analyzed. In this manner, the study determined the change of the effects of each IT capital stock and economy level and fragmentation of the study period unlike the existing studies.

Table 20.7 shows a summary of the results and the effects of each IT capital stock per economy level for the 30 years from 1975 to 2005. IT capital stock was found to have a significant impact on the gross output in all three levels of the economy: economy-wide, IT economy, and non-IT economy. In the case of the IT economy, all IT capital stock such as IT, CT, and Soft were found to have a statistically significant impact. In the case of the non-IT economy, only IT in the area of hardware significantly affected gross output.

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.

Each IT capital stock had a different impact on the economy levels during the 10 years from 1995 to 2005. 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. By contrast, software capital stock significantly affected the gross output in the non-IT economy. This is because of the growth of the IT economy and the improvement of the degree of use of software in accordance with the rapid expansion of the Internet after the late 1990s.

Table 20.7
Summary of Results

	Period	*IT*	*CT*	*Soft*	*IT labor*
H1: Economy wide	1975-2005	o	o	x	x
	1995-2005	o	o	x	o
H2: IT Economy	1975-2005	o	o	o	o
	1995-2005	x	o	o	o
H3: Non IT Economy	1975-2005	o	x	x	-
	1995-2005	o	x	o	-

Note: Null hypothesis is rejected is indicated by "o"

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 types, 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. Regarding countries with stable IT infrastructure, this study may be used as basic data for establishing a national development strategy based on the growth of the IT economy.

However, several limitations exist. For example, the number of target countries in this study is only 15, and the study is limited only to the non-IT economy even though numerous industries exist. Therefore, increasing the number of countries in subsequent studies and conducting studies by sorting the economic level of each country and the level of IT capital stock are imperative. In addition, it is possible to analyze the effects of each IT capital stock at each economic level by fragmentizing the non-IT economy.

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