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INFORMATION TECHNOLOGY INVESTMENT AND PRODUCTIVITY GROWTH IN KOREA

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This study analyzes the effect of IT investment on productivity growth based on Korean firm level data in 1996-2000. Empirical findings support the hypothesis that IT investment enhanced productivity by increasing value-added and saving ordinary capital and labor. Installed IT capital is estimated to be valued in the financial market much higher than the acquisition price. It implies that IT investment accompanies creation of unmeasurable intangible assets. Taking this into account, the contribution of IT investment to economic growth could be greater than suggested by conventional growth accounting. Strong structural reform after recent economic crisis might have helped IT investment to have a substantial impact on firm performance.

JEL Classification: O3, O4
Keywords: Information Technology, Total Factor Productivity, Intangible Capital, Growth Accounting

I. INTRODUCTION

This study tries to examine the effect of IT investment on productivity growth in Korea during the period 1996-2000 based on firm level data. The period 1996-2000 is a good sample period to find an impact of IT if there is any, since most Korean firms underwent drastic structural transformation along with huge IT investments. Based on the empirical results from the firm-level analysis, this study also tries to evaluate the role of IT investment in the economic growth of Korea.[1]

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Although recent recession in the U.S. cooled off the hype of new economy that new information technology leads to a world with high productivity growth and low inflation, we cannot deny the importance of IT as a driving force of current transformation of economy. Among many issues on IT, so called 'productivity paradox of computers' has engendered many studies investigating the impact of IT on the productivity both at macro and micro level. The productivity paradox with a saying that we can see computers everywhere except for the productivity statistics came from a series of studies presented in the late 1980s and early 1990s.[2] These studies analyzed extensive data of the 1970s and 1980s with various methodologies but found little evidence that IT increased productivity.

Growing number of studies dealing with more recent data, however, has reported positive effects of IT on the economic performance. Lichtenberg(1995) and Brynjofsson and Hitt(1995) found firm-level evidence that IT investments earned substantial returns. Unlike earlier studies that covered the data up until mid 1980s, they examined the firm level data of relatively recent period 1988-92. Dewan and Min(1997) investigated the same period 1988-92 for large U.S. firms and found that IT capital is a net substitute for both ordinary capital and labor, suggesting that the factor share of IT in production will grow to more significant levels over time. At macro-level, Jorgenson and Stiroh(1999) reported that computer capital have contributed to the U.S. economic growth more than other physical capital and there has been a rapid substitution of IT equipment for other forms of capital and labor in the 1990s. Oliner and Sichel (2000) also reported the high labor productivity growth in the late 1990s was mostly attributable to adoption of IT.

Most studies on this issue were done for the U.S. but the existing studies are rare for Korea.[3] It seems to be due to the lack of data on IT in Korea. For example, data on IT investments are not officially reported in Korea, while the U.S. government (Bureau of Economic Analysis) reports the IT-related investments separately from other types. Furthermore, firm level data are almost non-existent. We may mention all the existing Korean studies here. In country level, Lee(2000) calculated the contribution of IT investments to the growth of Korean economy for 1975-95 by using IT capital stock estimated by Shin, Kim,

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[1] Information Technology could be too broad to be defined in a single word. IT concerned in this study is the technology related with office, accounting, and computing equipment, which affects the operation of firms most. Thus IT capital in this study is computers and peripheral equipment.

[2] To name a few, Cron and Sobol(1983), Roach(1991), Loveman(1988), Strassman(1985, 1990), Morrison and Berndt(1991). For detailed review of papers, see Brynjolfsson and Yang(1996) and Kiley(2000).

[3] For the U.S. there are numerous studies in both country and firm level. To name a few, there are Oliner and Sichel(1994) and Jorgenson and Stiroh(1999) in country-level and Lichtenberg(1995), Brynjolfsson and Hitt(1995, 1996), and Brynjolfsson and Yang(1999) in firm-level. For the list of studies, see Brynjolfsson and Yang(1996) and Kiley(2000).

and Chung(1998). In firm-level, Shin, Kim, and Song(1998) investigated the relationship between IT spending and firm performance based on the survey of Korea Information Society Development Institute (KISDI). Kang and Song(1999) studied the effect of IT investments on productivity of the Korean banks during the period 1990-96 using the expense on computing as a proxy for IT investments. Based on the survey data, Lee(2000) exercised a similar study on firms in textile industry in Daegu and Kyungbuk area of Korea in 1998. The empirical results from these studies are mixed in evaluating the effect of IT on productivity. Lee(2000) reported that the contribution of IT investments based on growth accounting for 1976-95 was 0.39 percent per annum (4.89% of GDP growth), not so important compared to the U.S. (11.19% according to Oliner and Sichel(1994)). Other three studies approached the issue by estimating the marginal product of IT capital stock. Shin et al. (1998) and Kang et al. (1999) found that the marginal product of IT capital stock is higher than that of ordinary capital by two to five times. On the other hand, Lee(2000) found that the marginal product of IT capital was not so significantly different from zero.

This study is similar to the above studies in that it tries to find some evidence on the relationship between IT and productivity growth. However, this study approaches the issue in as many ways as possible to the furthest extent we can apply to the limited data. Moreover, unlike above studies, this study tries to extract some implications on the role of IT in the recent economic growth of Korea after 1997 economic crisis.[4] While most studies were done for the period before crisis, this study analyzes the period from 1996 to 2000 during when the Korean economy passed through the hit of 1997 crisis, following recession, and dramatic recovery with a considerable structural reform. This period of late 1990s also contrasts with the preceding periods in terms of IT diffusion and IT sector growth. According to Figure 1, IT investment rose sharply in the 1990s. Particularly, we notice the dramatic rise in IT investment compared with other types of investment in the last half of 1990s after crisis. It is due to the fact that the IT investment continued to rise despite the economic crises while total investment decreased.

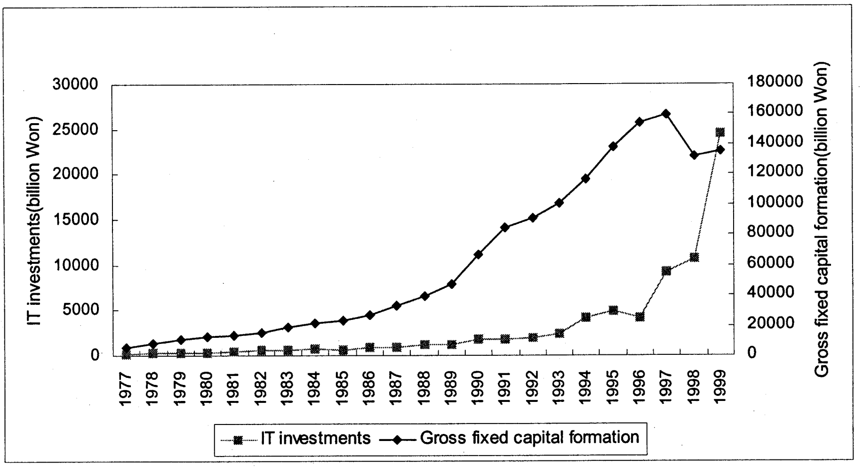
Along with dramatic increase in IT investment in 1997-2000, most Korean firms introduced unprecedented reform under the pressure of economic crisis. Many workers were laid off and many operations done internally were outsourced. Total investment declined with severe recession but IT investment rather accelerated as shown in Figure 1. It is well known IT reduces coordination and transaction costs and thus helps companies to adopt flexible coordination system. The coincidence of structural reform and massive IT

[4] The conventional growth accounting approach used by Lee(2000) cannot cover the spillover effect of IT investment on total factor productivity growth while this study take into account the intangible effect of IT investment. In addition to the estimation of marginal productivity of IT investment, this study analyzes the effect on firm-level total factor productivity and investor's firm valuation.

investment implies that IT investment could have worked as a complementary factor to the reorganization of Korean firms, a hypothesis this study explores.

Section 2 provides some empirical findings on the role of IT investment in firm productivity growth. First, a simple production function is estimated to compare marginal product of IT and ordinary inputs. Next, we examine the effect of IT spending on firm-leve total factor productivity. Finally, the valuation of IT capital in the financial market is estimated. Based on the firm-level findings, section 3 exercises a simple experimental growth accounting to see how much contribution IT investment might have made to the recent economic growth of Korea.

[Figure 1] Trends of IT Investment and Total Investment in Korea



Note: The data for the U.S. are obtained from the U.S. Bureau of Economic Analysis, where the IT capital is defined as computers and peripheral equipment, and office, accounting and computing machinery. IT investment for Korea is the 70% of the absorption of office, accounting and computing machinery calculated based on OECD STAN database. 70% of absorption is assumed to be the share of investment based on I-O table. IT investment is in constant prices.

Ⅱ. THE IT INVESTMENT AND FIRM-LEVEL PRODUCTIVITY

2.1. Marginal Product of IT investment

To start with, we estimate a simple Cobb-Douglas production function to calculate the marginal product of IT investment as much of the work (Berndt and Morrison(1995), Brynjolfsson and Hitt(1995), Lichtenberg(1995), Shin, Kim, and Song(1998)) in this area did. The production function is specified as

$$Y_i = A_i C_i^{\alpha} K_i^{\beta} L_i^{\gamma} \tag{1}$$

where Y_i, C_i, K_i, and L_i are defined as output, IT stock, non-IT fixed capital stock, and non-IT labor of firm i, respectively. A_i, an efficiency level of firm i, cannot be specified separately for each firm due to degree of freedom since we are using only one year cross-sectional data.[5] Instead, industry dummy variables are included in the regression to distinguish the sectoral differences.[6]

Output is defined as value added obtained from the financial statements provided by the National Information and Credit Evaluation. Non-IT fixed capital stock is obtained from the same source by subtracting IT capital stock from the fixed assets. Non-IT labor input is defined as total labor expense net of IT labor expense. The data on IT stock is obtained from the survey done by Korea Information Society Development Institute, the only available source of data on IT spending in firm-level.[7] Following Brynjolfsson and Hitt(1995), IT stock is defined so that it includes spending on both IT capital and labor. IT capital is a stock variable while IT labor expense is a flow variable. To combine the two into a single stock variable, it is assumed that current level of IT labor expense continued last several years and IT labor stock depreciates fully in three years. From this, we construct the IT stock that equals the sum of IT capital stock and three times IT labor expense.[8]

The production function in (1) is estimated by the ordinary least squares method in logarithmic form. Thus the estimated coefficient reported in Table 1 is the output elasticity.[9] All coefficients in the regression are statistically significant at 5 percent level and the output elasticity of labor is 0.87, somewhat

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[5] Since the data on IT spending are available only for 1996, a production function can be estimated by using the cross-sectional data of 1996.

[6] Industries are classified as fishery, mining, food and beverages, textiles, clothing, leather, wood and products, paper, printing, chemicals, petroleum, rubber and plastic products, non-metal, basic metal, metal products, industrial machinery, office and accounting machinery, electronic goods, electrical goods, transport equipment, shipbuilding, precision and optical instruments, utilities, construction, transportation, wholesale and retail, hotels, finance. More than 80 percent of firms in the sample belong to manufacturing. Since the financial statements do not report value added for firms in financial sector, firms in financial sector are not included in the analysis except for the profitability and market value analysis to be done later in this section.

[7] Unfortunately, the data are quite limited in its coverage. It was done in 1997 to the managers of the firms listed in the Korea Stock Exchange. The survey data from KISDI provide firm's IT capital stock in 1996 which includes IT assets more than one year durable such as hardware, peripherals, software, and networking facilities. Therefore, the data on IT capital stock from the survey are actually IT fixed assets plus software. Since the amount of software stock is not reported separately, we use this variable as IT capital stock.

[8] This approach is originally from the R&D accounting literature such as Hall(1993).

[9] The estimates are different from Shin, Kim, and Song(1998) which has higher estimate for elasticity of IT capital. Instead of using surveyed IT capital stock, they constructed IT capital stock by assuming steady state of IT capital stock growth. The assumption that IT capital stock growth is at steady state in the 1990s seems unrealistic and it makes their data sensitive to current IT investment.

higher than 0.6-0.7, the level usually taken in the analysis. Based on the estimates can be calculated the marginal product of each input. For example, the marginal product of IT stock($\frac{\partial Y}{\partial C}$) is $\alpha\frac{Y}{C}$. Since the ratios of input to output are different across firms, we utilize an arithmetic mean to compute the marginal product. On the average, our sample firms operate with IT stock, non-IT capital, and labor as much as 10, 197, and 52 percent of value added, respectively. The marginal product of IT stock is estimated to be 0.42, eight times higher than non-IT capital stock.

Since the estimated marginal product is gross of depreciation, taxes and other costs, we should subtract user costs (= interest rate + depreciation rate - the rate of expected capital gains) to compute the net returns. To get rough estimate of net returns, we assume depreciation rates of IT stock and non-IT capital stock to be 0.2 and 0.05, respectively, and expected capital gains on IT stock and non-IT capital stock to be -0.15 and 0.05, respectively, following the approximation of previous studies (Lau and Tokutsu (1992), Lichtenberg (1995)). Finally, we assume interest rate in Korea to be 0.15. The net returns to IT investment are -0.08 (= 0.42-(0.15+0.2+0.15)) and those to non-IT investment are -0.10 (= 0.05-(0.15+0.05-0.05)). The net returns are not so different as gross returns due to higher depreciation rate and declining price of IT stock. The result contrasts with Lichtenberg (1995) reporting that the net returns to IT investment in the U.S. are significantly positive.

[Table 1] Marginal Productivity of IT capital stock

Variables	Parameter Estimates	
Constant	0.3617 (0.8661)	
IT Stock (α)	0.0434* (2.2410)	
Physical Capital (β)	0.1057** (3.6153)	
Labor Expense (γ)	0.8736** (21.9116)	
Number of observations	225	
R^2	0.9269	
	Ratio to Value Added	Marginal Product
IT Stock	0.1024	0.4238
Physical Capital	1.9727	0.0536
Labor Expense	0.5209	1.6771

Note: The parameter estimates are those of production function specified in equation (1). The figures in parentheses are t-statistics. (*) and (**) denote significance at 5% and 1%, respectively.

2.2. Effect of IT Investment on Productivity

Next we analyze the relationship between IT investment and productivity of firms. After taking logarithms of equation (1) and differentiating with respect to time, we get

$$y_i = a_i + \alpha c_i + \beta k_i + \gamma l_i \tag{2}$$

where y_i, c_i, k_i, and l_i are growth rates of output, IT stock, non-IT capital stock, and non-IT labor of firm i, respectively. Therefore,

$$y_i - \beta k_i - \gamma l_i = a_i + \alpha c_i. \tag{3}$$

The left-hand side of equation (3) is growth rate of total factor productivity (TFP). It depends on growth in IT stock(c_i) as well as undetected firm-specific factors(a_i). Thus the faster IT stock accumulates, the faster TFP grows. Since we don't have time series of IT stock, we regress the conventional estimate of TFP growth on the level of IT stock defined as per worker IT stock.[10]

To compute TFP growth, output and capital input are defined as value added and fixed asset, respectively.[11] Labor input is defined as number of employees. The labor income share is computed as an arithmetic mean of labor expense divided by value added of firms in an industry a firm belongs to. Capital income share is one minus labor income share. Since TFP growth of a firm fluctuates along with firm specific business cycle in the short run, we use one year to four year TFP growth as dependent variables.[12] In the regression, we include industry and R&D dummy variables to control for the firm specific factors.[13]

Table 2 presents the relationship between IT stock and TFP growth. Although we cannot get statistically significant estimates for all the regressions, figures in Table 2 show a tendency that IT stock pays off with increase in TFP growth

[10] Under the constant returns to scale, we get $(y_i - l_i) - \beta(k_i - l_i) = a_i + \alpha(c_i - l_i)$ from equation (3). Therefore, the TFP growth of a firm depends on per worker IT stock.

[11] Value added and fixed asset are deflated by the deflators for GDP and gross fixed capital formation obtained from National Accounts, respectively.

[12] In fact, this exercise implicitly assumes that the relative IT stance of firms in 1996 continues for the following years. The correlation between 1995 and 1996 spending is quite high and it is quite plausible more IT utilizing firms continue high IT investments in the following years. In addition, the level of IT fixed capital stock in 1996 indicates the effort of a firm in IT utilization in the past. Considering the fact that it takes some years for IT investments to realize as enhanced performance, the relationship between IT investments and firm performance could be detected with some lags rather than contemporarily, if there is any.

[13] Since many firms do not have R&D expenditure, R&D effort is specified as a dummy variable that distinguishes firms with and without R&D expenditure.

by augmenting the value added and saving ordinary labor and capital.[14] It is consistent with the fact that IT investment stimulates the up-skilling of labor and thus increases value added per unit of input in operation. Table 3 shows the trend of labor up-skilling in Korea. The proportion of non-production workers increased in terms of employment and wage in the last two decades. Among non-production workers, the proportion of high-skill workers increased continuously over the period. It increased sharply from 1996 to 1998 in employment and wage. On the contrary, the share of low-skill non-production workers leveled off in the 1990s and declined in 1998. Recent structural reform seems to have replaced low-skill workers by high-skill workers. The estimated coefficients in Table 4 show that the sectoral difference in the speed of substitution of high-skill for low-skill workers significantly depends on IT investment. The impact of IT investment seems to be much higher in the 1990s than in the 1980s.

In sum, the empirical results implies that IT has radically changed the way products and services are produced and has accelerated the substitution of the low value-adding ordinary inputs for high value-adding IT intensive ones. Since most firms in Korea underwent unprecedented structural reform in the late 1990s, the impact of IT could have been much more substantial.

[Table 2] The Effect of IT Stock on the Growth of Firm TFP, Output, Employment, and Ordinary Capital

Period	TFP Growth	Output Growth	Employment Growth	Capital Growth
1996~97	0.0135* (2.3844)	0.0119* (2.0440)	-0.0039* (-2.0357)	0.0007 (0.2984)
1996~98	0.0085* (3.4566)	0.0067 (1.8912)	-0.0024 (-1.6420)	-0.0014 (-0.6987)
1996~99	0.0033 (1.7572)	0.0069* (2.8129)	-0.0012 (-1.0294)	-0.0018 (-1.1258)
1996~2000	0.0018 (1.3994)	0.0016 (0.8604)	-0.0008 (-0.7326)	-0.0018 (-1.3698)

Note: The estimates are coefficients of IT stock in each regression using TFP, output, Employment, and Ordinary Capital growth as dependent variable, respectively. Each regression includes constant, industry and R&D dummy variables. The figures in parentheses are t-statistics. (*) denotes significance at 5%.

[14] Dewan and Min(1997) estimated CES-Translog production function to find that the IT capital was a net substitute for both ordinary capital and labor in the U.S. for 1988-1992.

[Table 3] Employment and Wage Share by Worker Type in Korea (%)

Non-Production Worker		
	Employment	Wage
1981	35.9	51.4
1986	40.7	55
1991	49.1	57.6
1993	48.8	56.5
1996	52.3	59.9
1998	56.2	64.5

High-Skill Non-Production Worker		
	Employment	Wage
1981	9.6	21.2
1986	13.6	26.1
1991	13.5	22.4
1993	20.1	29.3
1996	23	32.1
1998	27.7	38.3

Low-Skill Non-Production Worker		
	Employment	Wage
1981	26.3	30.2
1986	27.1	28.9
1991	35.6	35.2
1993	28.7	27.2
1996	29.3	27.8
1998	28.5	26.2

Source: Kim(2001). High-skill non-production workers are manager, specialists, and engineers. Low-skill non-production workers include office attendants, clerk, and retail salesperson etc. See detailed classification in Kim(2001). The raw data are obtained from Report on Occupational Wage Survey of Korea Ministry of Labor.

2.3. Market Valuation of IT Capital

The empirical findings so far imply that IT investment has higher marginal product than ordinary capital and lead to higher TFP growth. However, the increase in IT investment alone cannot incur expected gains unconditionally. Firms usually pour their valuable resources into worker reeducation and retraining, adjustment in operational routine, and rearrangement of existing facilities to exploit the new technology. The difference of IT stock among firms in a similar industry may be due to the difference in potential capability of firms to adjust themselves to IT.[15] It means that installing IT capital is not free

[15] Brynjolfsson and Hitt(1995) found that the estimate of marginal product of IT capital is

and requires adjustment costs. However, the financial statements disregard the valuable intangible assets created through IT investment. For example, accounting system does not consider expenditure on worker training, software, R&D, and advertisement for brand building as investment although they raise the potential value of a firm. Instead, they are treated as expenses. If we take creation of intangible assets into consideration, the value of installed IT capital should exceed the acquisition price. Therefore, the installed IT capital should be valued in the stock market higher than the book value.

According to the neoclassical model, a firm maximizes the present value of profit flows, which is equal to market value of firm $V(0)$.

$$V(0)=\int_0^\infty u(t)\pi(t)dt \tag{4}$$

where $u(t)$ is a discount factor and $\pi(t)$ is profit at time t. The profit at time t is firm's revenue minus total cost. That is,

$$\pi(t)=pF(K_1,\cdots,K_J,I_1,\cdots,I_J,L)-wL-z_1I_1-\cdots-z_JI_J$$

where J types of capital stock(K) and labor(L) are combined to produce output with price p. Here, we introduce the adjustment cost of investment by specifying a production function as $F(K_1,\cdots,K_J,I_1,\cdots,I_J,L)$ following Lucas (1967). The function F, homogenous of degree one, is non-decreasing and concave in K and L, and non-increasing and convex in I. z_j is the acquisition price of capital j, and w is wage rate. Capital stock accumulates over time through investment(I_j) net of depreciation(δ_jK_j).

$$\frac{dK_j}{dt}=I_j-\delta_jK_j, \text{ for all } j=1,2,\cdots,J.$$

Then, the Hamiltonian is set up as

$$\begin{aligned}&H(K_1,\cdots,K_J,I_1,\cdots,I_J,L,t)\\&=(pF(K_1,\cdots,K_J,I_1,\cdots,I_J,L)-wL-z_1I_1-\cdots-z_JI_J)u(t)+\sum_{i=1}^{J}\lambda_i(I_i-\delta_iK_i).\end{aligned}$$

Here the Lagrangian multiplier λ_j represents the shadow value of one unit of installed capital j. Using the first order conditions and assumptions made above,

sensitive to how they estimate the production function. When they introduced firm specific fixed effects in the model, the marginal product of IT capital decreased by half from the estimate without fixed effects. They concluded the half of IT effect on firm performance may come from firm's intrinsic capability.

the stock market value of a firm is the sum of shadow values of various types of installed capital goods.[16] That is,

$$V(0)=\sum_{j=1}^{J}\lambda_j(0)K_j(0). \quad (5)$$

Here λ_j is a shadow price of capital j. If there is no adjustment cost, λ_j should be equal to unity. Thus, $(\lambda_j-1)K_j$ is the size of adjustment costs originating from the capital investment. For the analysis, we classify a firm's asset into three types; IT fixed asset, non-IT fixed asset, and other assets. The market value of a firm is the sum of equity and debt. The equity value of a firm is calculated by multiplying the average stock price and total issue of equities in December 1996.[17] The data on IT fixed asset is taken from KISDI survey. Non-IT fixed asset is computed as total fixed asset net of IT fixed asset. Other assets are calculated by subtracting total fixed asset from total asset.

Table 5 shows the estimates of market valuation of three types of capital assets. The estimated market value of IT capital is about 6.8 in 1996, which is much higher than 1, while those of other ordinary capital assets are below 1. It means one Won of IT capital asset is valued about 6.8 Wons in the stock market. If the stock market is efficient, IT capital, worth one Won when purchased, increases firm's value about 6.8 Wons once installed. It supports the hypothesis that there exists a significantly high adjustment cost in investing IT capital such as worker reeducation and retraining and organizational adjustment. Thus, the empirical result implies one Won worth of invested IT capital stock implicitly includes 5.8 Won worth of intangible assets accompanying IT investment.

[Table 4] Effect of IT Investment on Up-skilling of Labor

Period	Employment	Wage
1981~98	2.00* (3.29)	2.40* (3.32)
1981~91	0.14 (0.82)	0.44 (1.60)
1991~98	1.86* (3.06)	1.96* (2.77)

Note: The estimates are from Kim(2001). The dependent variable is the rate of change in the proportion of sectoral high-skill non-production worker. The explanatory variable is the average of 1990 and 1995 share of office, accounting and computing machinery in total sectoral investment obtained from Input-Output Table. The figures in parentheses are t-statistics. (*) denotes significance at 5%.

16 For the derivation of the market value of a firm, see the appendix.

17 December is when firms report the annual financial statements.

[Table 5] The Market Valuation of Various Assets in 1996

Asset Types	Parameter Estimates
IT Fixed Capital Assets	6.7617 (6.6359)
Non-IT Fixed Capital Assets	0. 8789 (46.1147)
Other Capital Assets	0.8844 (180.0090)

Note: The regression is done for equation (5). Regression includes constant, industry and R&D dummy, and advertisement as controls. The figures in parentheses are t-statistics.

Ⅲ. IMPLICATIONS FOR AGGREGATE ECONOMIC GROWTH

In this section, we experimentally extend the result from the previous section to the country-level productivity growth to estimate the contribution of IT investment on Korea's recent economic growth.[18] For our purpose, we utilize growth accounting analysis but the analysis is different from the conventional methodology. A production function is defined as in section 2,

$$Y = pF(K_1, K_2, I_1, I_2, L, t) \tag{5}$$

where K_1, I_1, K_2, and I_2 are IT capital stock, IT investment, non-IT capital stock, and non-IT capital investment, respectively. Here we introduce time(t) as a factor for technical progress. From the assumptions that the production function is linearly homogeneous and firms maximize profits under competitive market, we get

$$\begin{aligned} pF(K_1, K_2, I_1, I_2, L, t) &= pF_{K1}K_2 + pF_{K2}K_2 + pF_{I1}I_1 + pF_{I2}I_2 + pF_L L \\ &= r_1K_2 + r_2K_2 + (z_1 - \lambda_1)I_1 + (z_2 - \lambda_2)I_2 + wL \end{aligned}$$ [19]

Based on the empirical findings from the previous section, we assume that the shadow value of non-IT capital stock is not different from the replacement cost ($z_2 = \lambda_2$). Then,

$$Y = r_1K_1 + r_2K_2 + (z_1 - \lambda_1)I_1 + wL.$$

Therefore,

$$Y + (\lambda_1 - z_1)I_1 = r_1K_1 + r_2K_2 + wL.$$

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[18] The exercise in this section is experimental since our treatment of data and methodology are too crude and simple to be considered as precise estimation.

[19] It is from the first order conditions in the appendix.

The term $(\lambda_1 - z_1)I_1$ is due to the discrepancy between the shadow value and acquisition price of IT investment. It originates from the intangible assets created with IT investment. The cost of creating intangible assets such as software, worker retraining, and organizational reform to exploit the IT should be, in a true sense, counted as investment. However, in the balance sheet, they belong to expenses and are not included as investment in National Accounts. Thus true GDP of a country should be revised as GDP(Y) plus unmeasured investment in intangible assets(($\lambda_1 - z_1$) I_1).

Differentiating (5) with respect to time and dividing by Y, we get

$$\frac{\dot{Y}}{Y} + (\lambda_1 - z_1)\frac{\dot{I}_1}{Y} = \frac{r_1 K_1}{Y}\frac{\dot{K}_1}{K_1} + \frac{r_2 K_2}{Y}\frac{\dot{K}_2}{K_2} + \frac{wL}{Y}\frac{\dot{L}}{L} + \frac{\dot{A}}{A} \tag{6}$$

where $\frac{\dot{A}}{A} = \frac{pF_t}{Y} = \frac{F_t}{F}$.[20] The left hand side of the equation is GDP growth plus unmeasured creation of intangible assets.

Under the assumption of constant returns to scale, conventional total factor productivity growth is calculated as

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \alpha_1\frac{\dot{K}_1}{K_1} - \alpha_2\frac{\dot{K}_2}{K_2} - (1 - \alpha_1 - \alpha_2)\frac{\dot{L}}{L} \tag{7}$$

This conventional growth accounting excludes unmeasured investment of creating intangibles by imposing λ_1 equal to z_1. The empirical result in the previous section significantly rejects $z_1 = \lambda_1$. Therefore, if we take into account unmeasured investment accompanying IT investment, TFP growth could be revised as

$$\frac{\dot{A}}{A} + (\lambda_1 - z_{1)}\frac{\dot{I}_1}{Y} = \frac{\dot{A}}{A} + (\frac{\lambda_1}{z_1} - 1)\frac{\dot{I}_1}{I_1}\frac{z_1 I_1}{Y} \tag{8}$$

Therefore, the faster IT investment accelerates and the greater the share of IT investment is in total expenditure (GDP), the greater revised TFP growth exceeds conventional one. Considering that IT investment accelerated in 1996-2000, there would have been substantial IT-induced TFP growth disregarded in the conventional growth accounting.

To apply the above idea to Korean economic growth, output defined as real GDP is obtained from National Accounts. Labor is defined as total employment obtained from statistical yearbook. For our purpose, we define IT capital goods

[20] The price level, P and z_j, are fixed and thus the variables are real in constant prices. As above, we assume $z_2 = \lambda_2$.

narrowly as office, accounting, and computing machinery. National Accounts do not provide data on IT capital investment. Therefore, we estimate the IT capital investment from absorption of IT capital goods.[21] The absorption of IT capital goods is calculated by subtracting net export from gross output of office, accounting and computing machinery obtained from OECD STAN database. Since the absorption includes consumption as well as investment, we utilize the data from gross fixed capital formation of Input-Output Table. Input-Output Table has the data on gross fixed capital formation by detailed types of capital goods and classifies computers and office machinery as separate item. Thus we compare computed level of absorption and the amount of IT goods investment in 1990 and 1995 from I-O Table. It is found the ratios of investment to absorption in both years are approximately 0.7. Thus, we assume 70 percent absorption of IT capital goods is spent for investment. Since the absorption is in current prices, we deflate the data by using the producer price index of office machinery. Next, non-IT fixed capital formation is obtained by subtracting IT investment from total gross fixed capital formation. Both IT and non-IT capital stock are constructed by perpetual inventory method.[22]

Finally, we need the factor income share for each input. We may use the estimates of elasticities in table 1. Since we explore the aggregate productivity using different dataset from table 1, we adopt the traditional assumption on the income share. We start by assuming labor income share to be 0.6, the share usually taken by many studies in economic growth. Since we distinguish IT and non-IT capital stock, we need to allocate capital income share, 0.4, into the share of each type of capital. From the assumption that the rate of returns is equal to user cost, we get

$$\alpha_1+\alpha_2=\frac{r_1K_1}{Y}+\frac{r_2K_2}{Y}=\frac{(i+\delta_1-\pi_1)K_1}{Y}+\frac{(i+\delta_2-\pi_2)K_2}{Y}=0.4. \qquad (9)$$

As in the previous section, we assume δ_1, δ_2, π_1, and π_2 to be 0.2, 0.05, -0.15, and 0.05, respectively. The only unknown variable, interest rate(i), can be computed from the equation (9). After solving equation (9) for interest rate, we can easily compute the income shares of IT and non-IT capital, which turn out to be 0.0108 and 0.3892, respectively.[23]

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[21] Shin, Kim, and Chung(1998) constructed IT capital Stock. For our purpose, this dataset is not useful. First, it include too broad range of items such as electric cable, transformer, and telephone which cannot be included in true IT investment affecting firm performance. Second, it provides data only until 1995.

[22] As in section 2, we assume service life of IT capital goods is 5 years and that of non-IT capital goods is 20 years. That is, the depreciation rates of IT and non-IT capital goods are assumed to be 0.2 and 0.05, respectively. Benchmark capital does not affect data for 1980-2000 much since we accumulate the investment from the mid 1960s.

[23] According to table 1, elasticity of IT capital is 0.0434, higher than 0.0108 and that of

[Table 6] The Role of IT investment in Korean Economic Growth

	1981-85		1986-90		1991-95		1996-2000	
	Average Annual Growth Rate	Contribution (%)	Average Annual Growth Rate	Contribution (%)	Average Annual Growth Rate	Contribution (%)	Average Annual Growth Rate	Contribution (%)
Conventional GDP	7.525	100	9.056	100	7.188	100	4.751	100
IT Fixed Capital	0.216	3	0.163	2	0.211	3	0.394	8
Non-IT Capital	2.313	31	3.104	34	4.019	56	2.599	55
Employment	1.079	14	2.268	25	1.455	20	0.373	8
Conventional TFP	3.917	52	3.520	39	1.503	21	1.385	29
Hypothetical GDP	7.968	100	10.365	100	8.701	100	12.760	100
Hypothetical TFP	4.360	55	4.829	47	3.016	35	9.394	74
IT contribution	0.659	8	1.472	14	1.724	20	8.404	66

Note: The growth rate of revised GDP is constructed by assuming the shadow value of IT investment is 6 times greater than acquisition price. The growth rate of revised TFP is the growth rates of conventional TFP plus the growth rates of revised GDP minus the growth rates of conventional GDP. IT contribution is contribution of IT fixed capital accumulation plus contribution of revised GDP minus contribution of conventional GDP.

Table 6 presents the result of growth accounting of the Korean economic growth since 1980. The average GDP growth rates in the first row show that the Korean economy continued rapid growth until recent crisis at over 7 percent per annum. Economic growth in 1996-2000 declined due to severe recession in 1998. Next four rows decompose the output growth by showing the growth rate attributable to each factor of growth. In the 1980s, the economic growth was attributable in the largest share to TFP growth followed by non-IT capital accumulation. In the 1990s, the contribution of non-IT capital accumulation was highest. On the contrary, the contribution of IT capital stock to economic growth is not so high since the factor share of IT capital stock is small in spite of rapid growth of IT capital stock. It is noticeable that the accelerated IT capital accumulation in the late 1990s contributed as much as 8 percent of 1996-2000 growth, higher than previous periods.

Now, we use equations (6) and (8) to compute the hypothetical GDP growth that includes the disregarded unmeasurable investment coming with IT investment. The empirical findings of Table 5 show that the stock market value of IT fixed capital is about 6.8 times of acquisition price in 1996. As an experimental attempt, we impose λ_1/z_1 equal to 6 for 1980-2000.[24] The hypothetical GDP growth is slightly higher than conventional measure until 1995. However, with rapid growth of IT investment, the hypothetical output growth is ostensibly higher during the period 1996-2000. If we regard the output growth

physical capital is 0.1057 much lower than 0.3892. Thus, if we use the estimates from table 1, the contribution of IT capital will be higher and that of physical capital will be lower. However, qualitative results will not change at all.

[24] Following computation systematically depends on how we put λ_1/z_1. Since our sample firms are relatively big firms listed in KSE, the estimated shadow value of 6.76 may overestimate the unmeasureable investment.

due to unmeasured factors as TFP growth, the TFP growth in 1996-2000 based on hypothetical GDP is as high as 9 percent per annum.

Since the additional contribution of TFP growth in the above is attributable to IT investment, the overall contribution of IT investment is the sum of this and the contribution of physical IT capital accumulation. The overall contribution of IT investment was 8 percent of output growth in the early 1980s. It increased to more than 20 percent in the early 1990s. In the late 1990s, it contributed as much as 66 percent of economic growth. Although the experimental estimation of IT impact could be biased to be overstated due to data selection, our simple experiment indicates that the contribution of IT investment could have been quite substantial particularly in the late 1990s.

Ⅳ. CONCLUDING REMARKS

This study examined the effect of IT investment on productivity growth based on Korean firm-level data in 1996-2000. The overall empirical findings support the hypothesis that IT investment enhances productivity by increasing valued added and saving ordinary capital and labor. Installed IT capital is estimated to be valued in the financial market about 6.8 times of acquisition price. It implies that IT investment accompanies creation of intangible assets. Taking this into account, the contribution of IT investment to aggregate economic growth would be much greater than the figures provided by the conventional growth accounting.

Although this study found some evidence supporting the positive role of IT investment in enhancing the firm productivity, it needs further investigations. First, some studies found that the utilization of IT in a firm is closely related with firm-specific assets such as management ability. Since the data on IT investment are available only for 1996, cross-sectional analysis done in this study could not clarify enough the relationship between the IT intensity and firm specific factors. The panel data approach would bring about fruitful results on this issue. Second, the data include firms listed in the Korea Stock Exchange only. Therefore, our sample does not cover enough firms in Korea. It may lead to biases in the results. In addition, to appreciate fully the technological difference among industries, further detailed industry classification would be needed. Finally, finding the case stories on how the adoption of IT helped the reform of Korean firms would be needed to substantiate the empirical evidence this study found.

Appendix: Market Valuation of a Firm

Many studies trying to measure intangible assets have used the stock market valuation. For example, Griliches(1981) and Hall(1999) used this approach to measure the intangible assets created from R&D expenditure. Brynjolfsson and Yang(2000) adopted this approach to the analysis of market valuation of IT capital goods in the U.S.

The first order conditions for the optimization problem in section 2 are as follows.

$$\frac{\partial H}{\partial \lambda_j} = \dot{K}_j = I_j - \delta_j K_j, \quad \forall j \text{ and } \forall t$$
$$\frac{\partial H}{\partial K_j} = -\dot{\lambda}_j = pF_{Kj}u(t) - \lambda_j\delta_j, \quad \forall j \text{ and } \forall t$$
$$\frac{\partial H}{\partial I_j} = 0 = (pF_{Ij} - z_j)u(t) + \lambda_j, \quad \forall j \text{ and } \forall t$$
$$\frac{\partial H}{\partial L} = 0 = (pF_L - w)u(t), \quad \forall t$$

with transversality condition $\lim_{t\to\infty} \lambda(t)K(t) = 0$. Here, F_k is the partial derivative with respect to factor k. By using the first order conditions, transversality condition, and the assumption that the production function F is homogeneous of degree one, we get

$$\sum_{j=1}^{J} \lambda_j(0)K_j(0) = \sum_{j=1}^{J}(\lambda_j(0)K_j(0) - \lambda_j(\infty)K_j(\infty))$$
$$= \sum_{j=1}^{J}\int_0^\infty (-\dot{\lambda}_j K_j - \lambda_j \dot{K}_j)dt$$
$$= \sum_{j=1}^{J}\int_0^\infty (pF_{Kj}K_j + pF_{Ij}I_j - z_jI_j)u(t)dt$$
$$= \int_0^\infty (\sum_{j=1}^{J} pF_{Kj}K_j + pF_{Ij}I_j - z_jI_j) + pF_LL - wL))u(t)dt$$
$$= \int_0^\infty (pF(K_1, \cdots, K_J, I_1, \cdots, I_J, L, t) - zI_j - wL)u(t)dt$$
$$= V(0).$$

Therefore, stock market value of a firm is sum of shadow values of various types of capital goods. Without adjustment costs, the shadow value is close to the book value.

From the first order conditions, we note that the total cost of investing one unit of capital good, K_j, is $z_j - pF_{Ij}$ which is the sum of the acquisition (z_j) and the adjustment costs ($-pF_{Ij} > 0$). Compared with ordinary capital investment, IT investment may bring about additional costs of building complementary intangible assets. Then total cost of investing one unit of IT capital could be much higher than that of ordinary capital.

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