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10 Information Technology and Firm Performance in Korea

Jong-Il Kim

10.1 Introduction

Information technology (IT) has made a considerable contribution to the recent economic growth of Korea. Semiconductor, personal computer, and telecommunication equipments ranked first, third, and sixth in export in 2000, respectively (Annual Statistical Report of Korea). A recent Organization for Economic Cooperation and Development (OECD) report reveals that the productivity growth in Korea could be to the large extent attributable to the strength in IT manufacturing (Pilat and Lee 2001). Along with expansion of IT-manufacturing sectors in Korea, Korean firms have become more IT equipped, particularly after the economic crisis in 1997. This study tries to examine the effect of IT use on Korean firm performance in the late 1990s.[1]

The existing studies for Korean firms are not numerous due to the lack of data (Shin, Kim, and Song 1998; Kang and Song 1999; Lee 2000).[2] This study is similar to the existing studies in that it tries to find some evidence on the relationship between IT and firm performance. However, this study

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1. Information technology could be too broad to be defined in a single word. In this study, we define IT narrowly as technology related to office, accounting, and computing equipment, which affects the operation of firms most.

2. The only available source of data on firm-level IT spending is a survey done by Korea Information Society Development Institute (KISDI). It covers firms listed in the Korea Stock Exchange and provides data on IT labor and capital in 1996. Information technology capital reported in the survey includes hardware (personal computers, mainframe computers, and peripheries), software, and networking facilities (routers, server, cables, transmission equipment, and switching system). The IT labor is reported as number of IT staff and IT labor expense.

Table 10.1 Recent Trend of Information Technology Indexes in Korea

	1997	2001
Internet backbone networks	80	144
Subscribers to broadband Internet services (thousands)	14	7,810
Internet users (thousands)	1,630	24,380
Personal computers (thousands)	6,930	20,700
Telephone lines (thousands)	20,430	22,680
Mobile phones (thousands)	6,910	29,050
IT production (trillions of Korean Won)	75.5	150.3
IT value added (trillions of Korean Won)	39.1	70.2
GDP share (%)	8.6	12.9
IT export (US$ billions)	31.3	38.4
Workers in IT sector (thousands)	560	660
IT companies	9,397	17,719
IT venture companies	636	5,073

Source: Korea Ministry of Information and Communication.

Note: Broadband Internet services are XDSL, cable modem, LAN, B-WILL, and satellite Internet services. The Internet user is defined as an individual of age seven or older who regularly uses the Internet more than once a month. Workers represent waged employees.

approaches the issue to the furthest extent we can utilize the limited data. Whereas most studies analyze the period before 1997 economic crisis, this study pays attention to 1997–2000.

Table 10.1 shows how fast Korea rushed toward the information age between 1997 and 2001. The number of personal computers increased three times, and internet users rose by a factor of more than ten. Korea exceeded most developed countries in the diffusion of broadband Internet services in 2001: IT production increased about twice, pushing the IT share of the gross domestic product (GDP) to 12.9 percent. The venture company boom established many new successful IT venture companies registered in the KOSDAQ stock market.

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 the severe recession after the crisis, but IT investment accelerated instead (figure 10.1). It is well known that IT reduces coordination and transaction costs and thus helps companies to adopt flexible coordination systems. The coincidence of structural reform and massive IT investment implies that IT investment could have worked as a complementary factor to the reorganization of Korean firms, a hypothesis this study explores.

Section 10.2 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

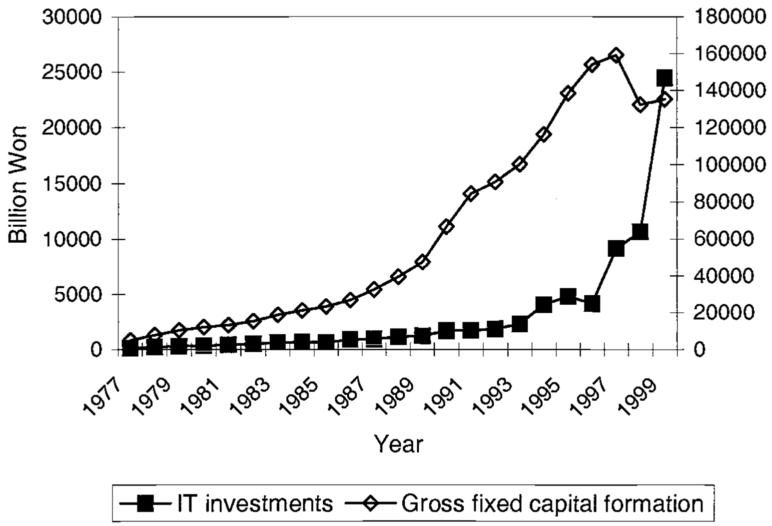

Fig. 10.1 Trends of Information Technology investment and total investment in Korea

Note: The data for the United States 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. For Korea, IT investment is the 70 percent of the absorption of office, accounting, and computing machinery calculated based on the OECD STAN database. Seventy percent of absorption is assumed to be the share of investment based on the input-output table; IT investment is in constant prices.

examine the effect of IT spending on firm profitability and total factor productivity. Finally, the valuation of IT capital in the financial market is estimated. Based on the firm-level findings, section 10.3 exercises a simple experimental growth accounting to see how much contribution IT investment might have made to the recent economic growth of Korea.

10.2 Information Technology Investment and Firm Performance

10.2.1 Marginal Product of Information Technology 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 in this area has done (Berndt and Morrison 1995; Brynjolfsson and Hitt 1995; Lichtenberg 1995). The production function is specified as

(1) $$Y_i = A_i C_i^{\alpha} K_i^{\beta} L_i^{\gamma},$$

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.[3] Instead, industry dummy variables are included in the regression to distinguish the sectoral differences.[4]

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. Following Brynjolfsson and Hitt (1995), IT stock is defined so that it includes spending on both IT capital and labor.[5] Information technology 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 IT labor expense stayed at the current level for the 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 the IT labor expense.

The production function in equation (1) is estimated by the ordinary least squares method in logarithmic form. Thus the estimated coefficient reported in table 10.2 is the output elasticity. All coefficients in the regression are statistically significant at the 5 percent level, and the output elasticity of labor is 0.87—somewhat higher than 0.6–0.7, the level usually taken in the analysis.[6] Based on the estimates the marginal product of each input can be calculated. For example, the marginal product of IT stock ($\partial Y/\partial C$) is $\alpha(Y/C)$. 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.

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

4. 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, and 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 the financial sector, firms in the financial sector are not included in the analysis except for the profitability and market value analysis to be done later in this section.

5. The survey data from KISDI provide firms' IT capital stock in 1996, which includes IT assets with more than one year's durability, 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.

6. Since a firm's decision on whether to spend on IT may depend on its productivity, there may be a selection and a simultaneity problem. Thus, our coefficient estimates could have a negative bias on capital and a positive bias on labor. See Olley and Pakes (1996).

Table 10.2 Production Function Estimates

Variable	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)	
No. 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	0.4550

Note: The figures in parentheses are *t*-statistics.
***Significant at the 1 percent level.
**Significant at the 5 percent level.

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 a 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 the 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 as different as gross returns due to the higher depreciation rate and declining price of IT stock. The result contrasts with that of Lichtenberg (1995), who reported that the net returns to IT investment in the United States are significantly positive.

10.2.2 Effects of Information Technology Investment on Profitability

Next, we examine whether IT stock improves a firm's profitability. The profitability is measured as the ratio of operating profits to total assets, and the index of IT investment is defined as IT stock per worker.[7] To control for firm-specific characteristics, we include capital intensity (per-worker total

7. Good performance in current profit or total profit may be a result of latent capital gains of assets that the firm holds. Thus it may be better to use operating profits than current or total profits.

Table 10.3 The Effect of Information Technology Stock on Operating Profits

Year	IT Stock	Capital Intensity	Sales Growth	Debt Ratio
1996	–0.0004	–0.0001***	0.0097**	0.0499
	(–1.7225)	(–3.2678)	(1.8407)	(0.2721)
1997	0.0000	–0.0001***	0.0406***	0.3136
	(0.0649)	(–2.7411)	(4.0173)	(1.4669)
1998	–0.0001	–0.0000	0.1604***	0.1877
	(–0.1607)	(–0.3860)	(6.5629)	(0.3022)
1999	0.0019***	–0.0000	0.0592***	–0.6575
	(3.3034)	(–1.2232)	(3.7472)	(–1.6378)
2000	0.0011	–0.0000	0.0745***	0.1066
	(1.4146)	(–0.2870)	(3.9818)	(0.1665)

Notes: The independent variable is operating profit of each year. Each regression includes constant and industry dummy variables. The figures in parentheses are *t*-statistics.

***Significant at the 1 percent level.

**Significant at the 5 percent level.

fixed assets), sales growth, the debt ratio (total debt over equity capital), and industry dummies.[8] Since profits could be influenced by short-term business fluctuation and idiosyncratic factors, we exercise the analysis for each year from 1996 to 2000.

Table 10.3 shows the empirical result. As expected, sales growth has a significant positive impact on a firm's profitability. The estimated coefficients of IT stock per worker are not significant except for 1999, and the signs of the estimates do not show any regularity. Considering the low estimates of the net returns to IT investment, it is not surprising that the IT investment does not have any significant effect on profits. Capital intensity also has a significantly negative effect in 1996 and 1997, which seems to be consistent with negative net returns to capital investment.

10.2.3 Effects of Information Technology Investment on Productivity

Next we analyze the relationship between IT investment and the 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,

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

8. Analyzing a firm's profitability with the regression method is problematic due to specification problems since it does not have any structural form and is affected by many omitted factors. We choose the controls following Strassman (1990).

Table 10.4 The Effect of IT Stock on the Growth of Firm TFP, Output, Employment, and Capital

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

Notes: Each regression includes constant, industry, and R&D dummy variables. The figures in parentheses are *t*-statistics.

**Significant at the 5 percent level.

The left-hand side of equation (3) is the 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.[9]

To compute TFP growth, output and capital input are defined as value added and fixed assets, respectively.[10] Labor input is defined as the 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 the firm-specific business cycle in the short run, we use one-year to four-year TFP growth as dependent variables. In the regression, we include industry and research and development (R&D) dummy variables to control for the firm specific factors.[11]

Table 10.4 presents the relationship between IT stock and TFP growth. Although we cannot get statistically significant estimates for all the coefficients, figures in table 10.4 show a tendency that IT stock pays off with increase in TFP growth by augmenting the value added and saving ordinary labor and capital.[12] It is consistent with the fact that IT investment stimu-

9. 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.

10. Value added and fixed assets are deflated by the deflators for GDP and gross fixed capital formation obtained from National Accounts, respectively.

11. 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.

12. Dewan and Min (1997) estimated a CES-translog production function to find that the IT capital was a net substitute for both ordinary capital and labor in the United States for 1988–92.

Table 10.5 Employment and Wage Share by Worker Type in Korea (%)

	Nonproduction Worker		Highly Skilled Nonproduction Worker		Low-Skill Nonproduction Worker	
Year	Employment	Wage	Employment	Wage	Employment	Wage
1981	35.9	51.4	9.6	21.2	26.3	30.2
1986	40.7	55	13.6	26.1	27.1	28.9
1991	49.1	57.6	13.5	22.4	35.6	35.2
1993	48.8	56.5	20.1	29.3	28.7	27.2
1996	52.3	59.9	23	32.1	29.3	27.8
1998	56.2	64.5	27.7	38.3	28.5	26.2

Source: Kim (2001).

Notes: Highly skilled nonproduction workers are managers, specialists, and engineers. Low-skilled nonproduction workers include office attendants, clerks, retail salespersons, and the like. See detailed classification in Kim (2001). The raw data are obtained from the Report on Occupational Wage Survey of the Korea Ministry of Labor.

Table 10.6 Effect of Information Technology Investment on Up-Skilling of Labor

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

Notes: The estimates are from Kim (2001). The dependent variable is the rate of change in the proportion of sectoral highly skilled nonproduction workers. The explanatory variable is the average of 1990 and 1995 share of office, accounting, and computing machinery in total sectoral investment obtained from the input-output table. The figures in parentheses are *t*-statistics.

**Significant at the 5 percent level.

lates the up-skilling of labor and thus increases value added per unit of input in operation. Table 10.5 shows the trend of labor up-skilling in Korea. The proportion of nonproduction workers increased in terms of employment and wage in the last two decades. Among nonproduction workers, the proportion of highly skilled workers increased continuously over the period. It increased sharply from 1996 to 1998 in employment and wage. In contrast, the share of low-skilled nonproduction workers leveled off in the 1990s and declined in 1998. Recent structural reform seems to have replaced low-skilled workers with highly skilled workers. The estimated coefficients in table 10.6 show that the sectoral difference in the speed of substitution of highly skilled for low-skilled workers significantly depends on IT investment. The impact of IT investment seems to be much higher in the 1990s than in the 1980s.

This empirical result of productivity growth without profit from IT investment does not contradict economic theory. Although IT has increased productivity and created substantial value for consumers, these benefits might have not resulted in higher profitability. That is, through IT investment, firms did not gain competitive advantage but maintained competitive parity and benefits of IT investment flew into consumer surplus.[13] However, IT has radically changed the way products and services are produced, and it has accelerated the substitution of the low value–adding ordinary inputs for high value–adding IT-intensive ones. It is consistent with the finding that the estimate of gross returns to IT investment is quite high but that of net returns is actually negative. Since most firms in Korea underwent unprecedented structural reform in the late 1990s, the impact of IT could have been much more substantial.

10.2.4 Market Valuation of Information Technology Capital

The empirical findings so far imply that IT investment has higher marginal product than ordinary capital and leads 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.[14] It means that installing IT capital is not free and requires adjustment costs. However, the financial statements disregard the valuable intangible assets created through IT investment. For example, the accounting system does not consider expenditures on worker training, software, R&D, and advertisement for brand building as an investment, although they raise the potential value of a firm. Instead, they are treated as expenses. If we take the 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 $V(0)$.

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

13. See Hitt and Brynjolfsson (1996).

14. Brynjolfsson and Hitt (1996) found that the estimate of marginal products of IT capital is 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 that half of IT's effect on firm performance may come from the firm's intrinsic capability.

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,

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

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 $F(K_1, \ldots, K_J, I_1, \ldots, I_J, L)$ (Lucas 1967). The function F, homogenous of degree one, is nondecreasing and concave in K and L, and nonincreasing 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 ($\delta_j K_j$).

$$\frac{dK_j}{dt} = I_j - \delta_i K_j, \text{ for all } j = 1, 2, \ldots, J.$$

Then the Hamiltonian is set up as

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

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, the stock market value of a firm is the sum of the shadow value of various types of installed capital goods.[15] That is,

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

Here λ_j is a shadow value 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.[16] The data on IT fixed assets are taken from the Korea Information Society Development Institute (KISDI) survey (1997). Non-IT fixed asset is computed as total fixed asset net of IT fixed asset. Other assets are calculated by subtracting total fixed assets from total assets.

Table 10.7 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

15. For the derivation of the market value of a firm, see the appendix.
16. December is when firms report their annual financial statements.

Table 10.7 The Market Valuation of Various Assets in 1996

Asset Type	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)

Notes: Regression includes constant, industry, and R&D dummies, and advertisement as controls. The figures in parentheses are *t*-statistics.

are below 1. It means one won of IT capital asset is valued at about 6.8 won in the stock market. If the stock market is efficient, IT capital worth one won when purchased increases a firm's value about 6.8 won once installed.

The market value of IT capital goods estimated in this study for Korean firms is somewhat lower than that for the U.S. firms estimated by Brynjolfsson and Yang (1997). They found that the market value for each dollar of installed IT capital goods is on the order of ten times greater than that for each dollar of ordinary capital goods. It is noteworthy the United States has the higher estimated shadow value of IT capital stocks in spite of a longer history of IT investment. If the higher market valuation of IT capital comes only from the short-term rent during the time gap between the identification of opportunity and actual realization of investment, the estimates for Korean firms should be greater than those for the U.S. firms. The fact that we have the estimates the other way round indicates that IT investment accompanies a series of complementary investments. Higher valuation of IT capital goods in the United States implies that U.S. firms with a longer history of IT investment have better organization and more intangible assets adjusted to the IT environment.

10.3 Implications for Aggregate Economic Growth

In this section, we extend the results from the previous section to country-level productivity growth.[17] 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 10.2,

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

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

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

(t) as a factor for technical progress. From the assumption that the production function is linearly homogeneous and firms maximize profits under competitive market, we get

$$pF(K_1, K_2, I_1, I_2, L, t) = pF_{K1}K_2 + pF_{k2}K_2 + pF_{I1}I_1 + pF_{I2}I_2 + pF_L L$$
$$= r_1K_2 + r_2K_2 + (z_1 - \lambda_1)I_1 + (z_2 - \lambda_2)I_2 + wL.^{18}$$

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,

$$Y = r_1K_2 + r_2K_2 + (z_1 - \lambda_1)I_1 + wL.$$

Therefore,

$$Y + (\lambda_1 - z_1)I_1 = r_1K_2 + r_2K_2 + wL.$$

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 costs 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, the true GDP of a country should be revised as GDP (Y) plus unmeasured investment in intangible assets: $(\lambda_1 - z_1)I_1$.

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

$$(6) \qquad \frac{\dot{Y}}{Y} + (\lambda_1 - z_1)\frac{\dot{I}_1}{Y} = \frac{r_1K_1}{Y}\frac{\dot{K}_1}{K_1} + \frac{r_2K_2}{Y}\frac{\dot{K}_2}{K_2} + \frac{wL}{Y}\frac{\dot{L}}{L} + \frac{\dot{A}}{A},$$

where $\dot{A}/A = pF_t/Y = F_t/F$.[19] 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 TFP growth is calculated as

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

This conventional growth accounting excludes the unmeasured investment of creating intangibles by imposing λ_1 equal to z_1. If we take into account unmeasured investment accompanying IT investment, TFP growth could be revised as

$$(8) \qquad \frac{\dot{A}}{A} + (\lambda_1 - z_1)\frac{\dot{I}_1}{Y} = \frac{\dot{A}}{A} + \left(\frac{\lambda_1}{z_1} - 1\right)\frac{\dot{I}_1}{I_1}\left(\frac{z_1I_1}{Y}\right).$$

Therefore, the faster IT investment accelerates and the greater the share of IT investment is in total expenditure (GDP), the greater revised TFP

18. It is from the first-order conditions in the appendix.
19. The price level, P and z_j, are fixed, and thus the variables are real in constant prices.

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 foregoing idea to Korean economic growth, output defined as real GDP is obtained from National Accounts. Labor is defined as total employment obtained from the statistical yearbook. For our purpose, we define IT capital goods 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.[20] The absorption of IT capital goods is calculated by subtracting net export of office, accounting, and computing machinery obtained from the OECD structural analysis (STAN) database from gross output. Since the absorption includes consumption as well as investment, we utilize the data from gross fixed capital formation of the input-output table. The 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 items. Thus we compare the computed level of absorption and the amount of IT goods investment in 1990 and 1995 from the input-output table. It is found that 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 the perpetual inventory method.[21]

Finally, we need the factor income share for each input. We start by assuming the 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 the 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

$$\text{(9)} \quad \alpha_1 + \alpha_2 = \frac{r_1 K_1}{Y} + \frac{r_2 K_2}{Y} = \frac{(i + \delta_1 - \pi_1)K_1}{Y} + \frac{(i + \delta_2 - \pi_2)K_2}{Y} = 0.4.$$

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 equation (9). After solving equation (9) for interest

20. Shin, Kim, and Chung (1998) constructed IT capital stock. For our purpose, this data set is not useful. First, it includes too broad a range of items, such as electric cable, transformers, and telephones, that cannot be included in true IT investment affecting firm performance. Second, it provides data only until 1995.

21. As in section 10.2, we assume the service life of IT capital goods is five years and that of non-IT capital goods is twenty 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.

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.

Table 10.8 presents the result of growth accounting of Korean economic growth since 1980. The average GDP growth rates in the first row show that the Korean economy continued rapid growth until the recent crisis at over 7 percent per annum. Economic growth in 1996–2000 declined due to severe recession in 1998. The 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. In contrast, the contribution of IT capital stock to economic growth is not as high, since the factor share of IT capital stock is small in spite of the 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 in 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 10.7 show that the stock market value of IT fixed capital is about 6.8 times acquisition price in 1996. As an experimental attempt, we impose λ_1/z_1 equal to 6 for 1980–2000.[22] 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 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. Our simple experiment indicates that the contribution of IT investment could have been quite substantial, particularly in the late 1990s.

10.4 Concluding Remarks

This study examined the effect of IT investment on Korean firm performance in 1996–2000. The overall empirical findings support the hypothe-

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

Table 10.8 The Role of Information Technology 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
Revised GDP	7.968	100	10.365	100	8.701	100	12.760	100
Revised 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

Notes: The growth rate of revised GDP is constructed by assuming the shadow value of IT investment is six 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. The IT contribution is contribution of IT fixed capital accumulation plus contribution of revised GDP minus contribution of conventional GDP.

sis that IT investment enhances productivity by increasing value added and saving ordinary capital and labor. Installed IT capital is estimated to be valued in the financial market at about 6.8 times acquisition price. It implies that IT investment accompanies the 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 firm productivity, it needs further investigation. 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 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. This may lead to biases in the results. In addition, to appreciate fully the technological differences 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.

The first-order conditions for the optimization problem in section 10.2 are as follows.

$$\frac{\partial H}{\partial \lambda_j} = \dot{K}_j = I_j - \delta_j K_j, \quad \forall j \text{ and } \forall t \qquad \frac{\partial H}{\partial K_j} = -\dot{\lambda}_j = pF_{Kj}u(t) - \lambda_j \delta_j, \quad \forall j \text{ and } \forall t$$

$$\frac{\partial H}{\partial I_j} = 0 = (pF_{Ij} - z_j)u(t) + \lambda_j, \quad \forall j \text{ and } \forall t$$

$$\frac{\partial H}{\partial L} = 0 = (pF_L - w)u(t), \quad \forall t,$$

with transversality condition $\lim_{t\to 8}\lambda(t)K(t) = 0$. 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

$$\begin{aligned}\sum_{j=1}^{J}\lambda_j(0)K_j(0) &= \sum_{j=1}^{J}[\lambda_j(0)K_j(0) - \lambda_j(\infty)K_j(\infty)] \\ &= \sum_{j=1}^{J}\int_0^{\infty}(-\dot{\lambda}_j K_j - \lambda_j \dot{K}_j)dt \\ &= \sum_{j=1}^{J}\int_0^{\infty}(pF_{Kj}K_j + pF_{Ij}I_j - z_j I_j)u(t)dt \\ &= \int_0^{\infty}\left[\sum_{j=1}^{J}(pF_{Kj}K_j + pF_{Ij}I_j - z_j I_j) + pF_L L - wL\right]u(t)dt \\ &= \int_0^{\infty}[pF(K_1, \ldots, K_J, I_1, \ldots, I_J, L, t) - zI_j - wL]u(t)dt \\ &= V(0).\end{aligned}$$

Therefore, the stock market value of a firm is the 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 the 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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Comment Chong-Hyun Nam

This is a very interesting piece of empirical work, and I enjoyed reading it. I have only a few comments to make.

My first comment is concerned with the problem of data limitation. The empirical work in the paper is based on a very limited data set, just one-year IT (information technology) investment data for 225 micro firms for

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1996. The paper shows very well how much mileage one could get out of this limited data set in analyzing the effect of IT investment on the performance of the Korean firms and of the Korean economy. But the problems with data limitation remain.

A problem with the IT investment data as used in the study is that they are based on a narrow definition of IT capital. The IT capital used here includes only office and accounting equipment and computing machinery. So it leaves out such important IT capital goods as information equipment and other IT-related electrical products. These kinds of capital goods turn out to comprise more than 25 percent of IT investment for Japan, as shown in the paper by Fukao and others (chap. 6 in this volume). I suppose, therefore, the paper may need to discuss consequential effects expected from this data problem.

Another problem with the IT data is that the paper assumes that relative IT investment share in total capital investment stays rather stable over time or increases at an annual rate of 10 percent for the sample period 1996–2000. This assumption seems to me too naive, however. Indeed, as shown in figure 10.1, the share of IT investment in total fixed capital formation increases sharply beginning in 1996 from about 2 percent to over 12 percent in 1999. So the growth rate of IT investment needs to be adjusted accordingly to make it a more realistic value, I think.

My second comment has to do with the choice of sample period for the study, namely, the 1996–2000 period. The author argues that the 1996–2000 period is likely to be a good one since drastic structural transformation was taking place along with huge IT investment in Korea for this sample period. But I am not so sure that this argument is true, because it looks to me rather difficult to separate out the effects of IT investment from the effects of other policy reforms undertaken in the same period in accounting for the sources of growth for the Korean economy.

As is well known, the 1996–2000 sample period represents one of the most turbulent periods that the Korean economy has ever experienced. This period includes, for example, the 1997 financial crisis, which quickly developed into an economic crisis in 1998, registering a minus 6.7 percent growth rate with more than a 7 percent unemployment rate for 1998.

A number of reform measures were, therefore, undertaken by the government to get the economy out of the deep economic crisis. They include, for example, the cleaning up of the ailing financial sector, accelerated privatization, improvements to labor market flexibility, and so on. At the same time, the government placed strong pressure upon the firms to reorganize, to improve their governance system and their debt structure, and to make their production lines more lean and specialized in their products.

All of these reform measures should have had tremendous impact on the efficiency of the Korean economy, and they helped the economy to get back to a 10 percent annual growth rate again by 1999. I hope the author tries to illustrate some of these policy reforms undertaken during the sample period somewhere in the paper and discusses their potential or consequential impact on the measured contribution of IT investment on total factor productivity growth (TFPG) for the Korean economy.

Another problem with the sample data period 1996–2000 is that it includes a period of unprecedented stock market bubble. For instance, the KOSDAQ index, which is equivalent to the NASDAQ index in the United States, rose from about 80 in late 1998 to over 250 by the end of 1999, but then plummeted to 52 by the end of 2000.

The presence of the stock market bubble during the sample period could have grossly inflated the market value of IT capital to some unknown degree, and the inflated market value of IT capital in turn would have led to an unrealistically high estimate for revised value added, revised TFP, and the extent of IT capital's contribution to economic growth for Korea, as shown in table 10.8.

My final comment is that, given the fact that the sample period 1999–2000 includes a period of severe recession and high unemployment in Korea, it seems quite sensible to test the importance of capacity utilization rate as a determinant of TFPG. The study by Fukao and others shows that capacity utilization rate turns out to be an important determinant of TFPG in the case of Japan.

Comment Dipinder S. Randhawa

Jong-Il Kim provides a nicely structured and informed assessment of the impact of investments in information technology (IT) on firm performance in Korea between 1996 and 2000. The paper concludes that IT investments enhanced productivity by adding value to firms and saving capital and labor. He finds value added reflected further in the finding that the market values investments in IT substantially higher than the acquisition price.

The research question is one of the important issues of our times—the contribution to productivity arising from the substantial investments in information technology. The dilemma in computing the contribution of IT to productivity is evident in two paradoxes: the first at the macro level, encapsulated in the enduring words of Robert Solow dating back to 1987: "we can see the computer age everywhere but in the productivity statistics" (quoted in Brynjolfsson and Hitt 1998). Studies in 1999 and 2000 examining other manifestations of the IT revolution, especially the stock market boom and the resultant increase in spending, deemed the paradox re-

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solved. Events since have of course made this line of reasoning redundant and re-ignited the debate. The second paradox at the firm level is reflected in the inability to find any correlation between IT expenditures and measures of profitability.

At a broader level, a recent NBER paper by Robert Gordon (2002) questions whether the postulated increase in productivity on account of investments in IT in the United States was a one-shot injection in productivity or a productivity increase maintained by the extraordinarily high levels of IT investments until the late 1990s, or whether it has indeed led to a sustained increase in productivity. The same questions are pertinent for the Korean experience.

The Empirics

The studies on the impact of IT on productivity in the Korean economy offer conflicting evidence. Kim offers an articulate and comprehensive account of the major issues in measuring productivity. Five series of tests are conducted to gauge the impact on firm performance:

1. Using a modified Cobb-Douglas production function, investment in IT is treated as an additional factor of production. The marginal productivity of IT investments is computed.
2. To assess firms' profitability, turn to firms' financial statements.
3. For firms' productivity, compute total factor productivity.
4. Market valuation is drawn from firms' stock price.
5. Finally, a growth accounting exercise is used to see how much IT investments affected economic growth toward the end of the 1990s.

The expectation is that the use of a number of metrics would provide a comprehensive and nuanced view of firm performance. Kim notes that the benefits from IT spending lie in reduced coordination and transaction costs, making it easier for companies to adopt flexible coordination system over rigid hierarchical organization.

Kim further notes that during 1997–2000 many Korean firms introduced unprecedented reform of internal organization and corporate governance structure. Although overall fixed investments fell, investment in IT accelerated. Coincidence of structural reform and massive IT investments may imply that IT investments could have worked as a complementary factor to reorganization of Korean firms. The postcrisis period has arguably been one of unprecedented turmoil. A sizable body of literature has documented structural reforms in the corporate sector encompassing the streamlining of operations and management of the capital structure of firms. The largest *chaebols* have not been immune to change. At a time when firms are attempting to rehabilitate their balance sheets to stave off bankruptcy, it is a moot point whether they will have the incentives or the wherewithal to invest in IT on a large scale.

The current work assesses the contribution of IT to firms on the basis of IT spending. The impact of IT spending on a firm can be measured in different ways: (1) as the author has done, in terms of expenditure on IT; (2) on the nature of investments in IT; and (3) by examining the efficiency with which IT investments are managed within the firm.

In order to gain insights into how firms were responding to the crisis, one needs considerably disaggregated sector-level data on IT investments. I share Jong-Il Kim's clearly enunciated concerns about the lack of data. Data problems for such research projects have been endemic, and this paper is no exception. Data on IT spending at the firm level is available only for 1996. Kim extrapolates these numbers over the next three years to gauge the impact of IT. The time frame for the study coincides with the period when IT expenditures in Korea grew at an exponential rate. Assuming a correspondence between expenditures for the reported year and a linear extrapolation of this data for the next three years could lead to considerable distortions. Firms' strategies and corresponding expenditures on IT vary significantly across years and across firms. This extrapolation could lead to a misleading picture of firms' investments in IT.

The sample consists of firms listed on the Korean Stock Exchange. Most of these firms would be among the largest firms in the economy. Evidence from the United States has shown that small and medium-sized enterprises, especially the latter, have adopted some of the most robust strategies for IT investments. Few, if any, of these firms are listed, as most do not meet the minimum listing requirements. These firms have also demonstrated some of the most impressive productivity improvements following IT investments. The absence of this class of firms could conceivably understate the contribution of IT to productivity. Furthermore, studies have found significant differences across industries.

The results, as seen in table 10C.1, are mixed, offering no clear evidence on the impact of IT spending on firm performance. When measuring productivity it isn't clear whether the results reflect a substitution of inputs or an increased efficiency (i.e., a shift along the isoquant or a shift in the isoquant). Furthermore, the data do not enable us to identify the channels through which IT spending benefits the firm. The marginal increase in productivity without a commensurate increase in profitability suggests that

Table 10C.1 Effects of Information Technology Investments

	Impact
MP of IT capital	net returns = 0
Profitability	insignificant
Productivity	TFP growth 1% per annum
Market valuation of IT capital	by a factor of 7

the substantial costs incurred on IT investments negate the increases in productivity. The contradictory results for profitability and market valuation reflect a myopia, at worst outright mispricing in the market, an anomaly seemingly rectified following the market crash in 2001.

The Institutional Context

A useful corollary drawing upon the American experience is the role of universities, government research funding, and purely commercial enterprises in nurturing and disseminating IT innovations.

An explanation for the uneven adoption and dissemination of IT between the United States and Europe draws upon labor market regulations. Labor market regulations can have a profound impact on the adoption and dissemination of IT investments both at the firm and economywide levels—the contrast between Europe and the United States suggests they are significant for explaining cross-country differences in performance. It may be useful to examine this issue in the Korean context given the powerful union movement.

The spurt in IT spending in Korea lagged behind that in the United States by nearly a decade.

As the author points out in an analogy with the benefits from the introduction of electricity, there may well be a considerable lag before the beneficial effects of IT investment percolate down in the economy. An important question for researchers is identification of the channels through which these benefits manifest themselves. With the limited data resources, Kim has done an admirable job of providing a fairly comprehensive overview of the impact of IT spending.

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