THE KOREAN ECONOMIC REVIEW
Volume 20, Number 2, Winter 2004

DOES INFORMATION & COMMUNICATION TECHNOLOGY(ICT) INVESTMENT CONTRIBUTE TO COST REDUCTION?: AN EMPIRICAL ANALYSIS OF KOREAN INDUSTRIES*

KI-DONG LEE**

This paper investigates the cost reducing impact of ICT related investment along with substitution possibilities between ICT equipment and other inputs. The empirical analysis is based on a translog cost function model and annual data for a set of the Korean manufacturing industries (1984-99). Reflecting rapid increase in ICT investment in the 90's, the ratio of ICT capital to non-ICT capital (ICT intensity) rose from 1.79% in 1984 to 6.66% in 1999. We examine the cost saving effect of ICT capital by estimating the cost/ICT-capital elasticities. For most industries, our estimated cost/ICT-capital elasticities are negative as expected. However, cost reducing impacts of ICT capital are statistically supported in such industries as all industries belonging to assembly & processing industries, printing industry of consumer goods industries, and metal fabricating of basic material manufacturing industries. We also investigate the relationship between ICT-capital and other inputs by estimating the Allen elasticities of substitution and input demand elasticities with respect to ICT capital in the manufacturing sectors.

JEL Classification: O33, O47
Keywords: Cost Reduction, Cost/ICT-Capital Elasticity, Elasticities of Substitution

Ⅰ. INTRODUCTION

Although there have been large investments in ICT goods and services, existing empirical studies of the relationship between ICT investment and

Received for publication: Dec. 24, 2003. *Revision accepted:* Nov. 15, 2004.
* The author thanks Myunghun Lee(Keimyung University) and two anonymous referees for their comments and suggestions on an earlier drafts.
** Associate Professor, Department of International Trade and Commerce, Keimyung University, Daegu 704-701, Korea, and Visiting Fellow, Department of Economics, University of Washington, Seattle, WA 98195, U.S.A. Phone: +(425)-702-2103; Fax: +(206)-685-7477; E-mail: kdlee@kmu.ac.kr

productivity have yielded conflicting results.[1] Also in the Korean case, the economic impact of ICT investment has been analyzed employing various econometric methodologies(Shin et al., 1998; Kang and Song, 1999; Lee 2000; Kim and Lee, 2001; Bank of Korea, 2000; Kim, 2003, etc.). Despite increasing our understanding of the role of ICT in productivity improvement, these studies are subject to some limitations particularly in the Korean case.

First, cost functional approaches are needed in order to capture not only the cost reducing impact of ICT equipment but also the structure of production - especially the substitution possibilities among inputs. It is somewhat surprising that there are few rigorous analyses for the Korean case which explicitly take the cost reducing effects of ICT capital into account. As Morrison(1997) described, a fundamental concern in establishing the impact of ICT investment involves quantifying the cost effects of such investment, which requires capturing the linkages among inputs including ICT capital.

Second, many researches have been done at the economy-wide level using aggregated data, but we have relatively few studies using industry level data. In general, aggregate level analysis is appropriate for analyzing the economy-wide productivity or social return of investments. However, considering the facts that many other factors also affect productivity and that, until recently, ICT equipment was not a major share of the economy, the study at the economy-wide level is a rough approach. Firm-level analysis on the one hand helps to control for many problems that arise from aggregation, but on the other hand the results can hardly be applied to other industries or generalized for the whole economy. This implies that industry level studies are needed as a middle-of-the-road alternative for analyzing the effects of ICT investments.

Third, the effectiveness of adopting a simple functional type can be doubted. The Cobb-Douglas specification, which is very popular in empirical studies, has gained its merit due to the reason that the number of parameters to be estimated is small. As this type of function assumes a constant elasticity of substitution, it is inadequate to analyze the substitution possibilities among inputs. This implies that a more flexible type of function is needed, which does not, a priori, impose particular restrictions but rather permits these aspects to be established by the parameter values.

In this paper, we examine the cost reducing impact of ICT investment and substitution possibilities among inputs including ICT capital with a translog cost function model and the data for the Korean manufacturing industries. The paper proceeds as follows: In Section Ⅱ, we first discuss the theoretical background for the inter-industry productivity spillover of ICT investment. Then we go on to measure the level of the Korean ICT capital stock by industries. Section Ⅲ develops an econometric model to examine the impact of ICT equipment on the

[1] A number of studies which analyze the effects of ICT investment on productivity have been published. See Brynjolfsson and Yang(1996) for a review of most of these studies.

cost side. Data sources and the method of data construction are presented in Section Ⅳ. Section Ⅴ reports the empirical results of our estimates of the translog type variable cost function emphasizing ICT capital. Conclusions are given in the last section.

Ⅱ. PRODUCTIVITY EFFECTS OF ICT AND THE MEASUREMENT OF ICT CAPITAL STOCK

1) Productivity effects of ICT investment [2]

In general, it is said that ICT investment is an economic activity which is accompanied by positive externalities. Thus rapid growth in the ICT sector contributes not only to the productivity improvement in the ICT sector itself but also to productivity gain of other industries which increase the ICT investment by purchasing the investment goods from the input supplying ICT sectors.

One of the most important channels of ICT spillover is the improvement of the quality and/or production process of the inputs. This, in turn, is mainly the result of the R&D activities of the input supplying ICT industries. Most of the ICT industries produce R&D intensive goods. Thus the fruits of ICT manufacturers' R&D efforts, as embodied in investments goods, may be captured partially by the buying firms. Through this channel, the R&D effort of the ICT manufacturers is expected to spill over to the productivity growth of the buyer industries.

If the quality of the final goods in the buying industry improves by using the investment goods supplied by the ICT sector, the industry will receive the fruits of R&D activity of the ICT sector. Of course, the buying industry pays the price to the ICT sector; however, due to the rapid technological progress, the price of ICT goods has decreased or has risen little while quality has increased dramatically. This suggests that a substantial part of the fruits of R&D carried out by ICT industries has been captured by user industries. In this paper, by estimating the translog cost function, we investigate how the technological factor embodied in the flow of investment goods from the ICT industries contribute to the cost reduction in the buying industries.

2) The measurement of ICT capital stock

In order to examine the cost savings from ICT related investment, time series data of real investment and stock of such equipment at industry-level is indispensable. Unfortunately, since such information about the Korean manufacturing industries is not readily available, we will undertake the

[2] For further theoretical discussions about the spillover effects of ICT capital, see Shapiro and Varian(1999), Schreyer(2000), and Bank of Korea(2000).

measurement ourselves. For this, we adopt the industry classification of the Korean Input-Output table(hereafter I-O table), which classifies the manufacturing sector into 13 industries: food and beverage, textile and leather, paper and wood, printing(these belong to consumer goods industries), chemicals, petroleum, nonmetallic minerals, primary metals, metal fabricating(these belong to basic material manufacturing industries), general machinery, precision instruments, transportation equipment, and electronics(these belong to assembly & processing industries).

As a first step for our measurement, following the classification of the Korean National Statistics Office, we define the ICT sector to consist of the three following categories[3] : namely ⅰ) manufacture of information and telecommunication equipment, ⅱ) information and telecommunication equipment services, and ⅲ) software related activities. These three categories are divided into seven sub-categories, where each of these sub-category includes very detailed product items(see Appendix A). Appendix A represents how the product items in the ICT sectors match with the classification of the I-O table.

Based on the ICT classification and code matching with I-O tables mentioned above, we can estimate the ICT investment in each industry as the distribution of investment goods from the ICT sector to the corresponding industry.[4] Therefore, to generate ICT investment data using I-O tables, it is necessary to collect investment expenditures at a detailed level and then aggregate them over many different investment goods sources.

The total value of investment goods, which are supplied from the ICT sector to the buying industry, is treated as the value of ICT investment in the corresponding buying industry. The ICT capital stock at time t is equal to the stock in some benchmark year plus the sum of net ICT investment in all subsequent years including t. To generate ICT investment data, we use the I-O tables from 1980 to 1998. The Korean I-O tables, however, report only the total invested value of products in a industry and do not provide any information on how they are distributed to other industries. Thus, we assume that the distribution ratio of investment is the same as the one of intermediate inputs in all sectors.

Using this method, the ICT investment in the jth industry which is supplied

[3] In the Report on the Information and Telecommunications Survey of 1997(RITS), the Korean National Statistics Office identify five categories as ICT sector. In the current study, however, the next two categories— "information and telecommunication construction" and "wholesale and retail trade of information and telecommunication equipment" — were excluded from the ICT sector, because they bear very small share in the total tangible fixed assets.

[4] There are two reasons for using I-O tables in measuring the ICT investment by industries. First, we can get the ICT investment time series data by industries using the I-O tables. Since the Report(RITS) only covers the time after 1998, we cannot follow the time series including up to 1997. Second, since the I-O tables presents information on intermediate flows of products and services, it is possible to trace the distribution pattern of ICT investment which is needed to calculate the ICT capital stock in each industry.

by the ith ICT sub-category(ICT_{ij}) can be calculated as

$$ICT_{ij} = ICT_i \times \frac{X_{ij}}{\sum_j X_{ij}} \tag{1}$$

where ICT_i =nominal value of annual investment in ith ICT sub-category; X_{ij} =intermediate input(or demand) of the ith ICT sub-category's products purchased by jth industry; and $X_{ij} / \sum_j X_{ij}$= distribution ratio of intermediate inputs from ith ICT sub-category to jth industry. We replaced the data which could not be obtained from the I-O tables[5] with proxy observations obtained by linear extrapolation.

Since the amount of ICT investment derived from equation (1) is in nominal terms, the price index is needed to get the constant price capital stock. Unlike in the U.S., there is no official hedonic price index for ICT equipment in Korea.[6] Therefore, we construct the price index of ICT assets(PI) for each of the seven ICT sub-categories as follows. First, the producer price indices of products belonging to each sub-category are selected from the Economic Statistics Yearbook(ESY) of the Bank of Korea. Then, using the producer price index's weight, weighted averages of these price indices are calculated in order to generate the quality adjusted price index for ICT assets in Korea. Finally, we normalize the 1995's index to 100.[7]

Once the industry-level time series data on real ICT investment are obtained, a corresponding capital stock of this equipment can be computed. The approach, is the so-called the perpetual inventory method, and uses the relation,

$$R_{ij,t} = VICT_{ij,t} + R_{ij,t-1} \cdot (1-\delta) \tag{2}$$

where $VICT_{ij,t}(= ICT_{ij,t}/PI_{i,t})$=real value of ICT_{ij} at year t, $R_{ij,t}$ =real ICT capital stock that has been accumulated in industry j up to year t by the investment inflows from the ith sub-category of ICT sector, and δ =the constant depreciation rate. An annual depreciation rate of 22.4% is assumed for

[5] The Bank of Korea has published Input-Output tables every three to five years since the initial compilation of the 1960 Input-Output tables. During the time horizon of this study, the I-O tables were published in 1985, 1990 and 1995 and the updated extension tables were published in 1986, 1987, 1988, 1993 and 1998.

[6] One way of estimating a constant-quality price index a hedonic price index which makes use of a hedonic function. The hedonic function is a regression involving the price of some product(such as computers) and the characteristics of that product(for computers; processor speed, memory size, presence of sound cards and other features).

[7] Concerning the procedure mentioned above, it is necessary to indicate the following limitation with regard to the price index for ICT assets and the estimated ICT-capital stock: since the producer price indexes used to calculate the weighted average do not fully reflect the quality change, there maybe downward bias in the estimated ICT capital stock.

the ICT capital stock like other studies such as Lee(2001) and Shin et al.(1998).

Assuming that the annual growth rate of $VICT$ is the same as the growth rate of R, the initial stock of ICT capital($R_{ij,84}$) is obtained as $R_{ij,84}=\frac{VICT_{ij,85}}{\delta+g_{ij}}$, where g_{ij} is the average annual growth rate of $VICT_{ij,t}$ from 1984 to 1998. As this is an admittedly rough technique, so the estimated stocks of capital during the first few years are sensitive to the initial value of ICT stock and are therefore unreliable. But as the stocks of the initial year depreciated away, the overall estimate becomes more accurate over time.[8] Based on the initial value of the industry-level ICT capital stock, the corresponding capital stock time series can be computed using equation (2). Then by aggregating with respect to i, the ICT capital stock for industry j at time period t, $R_{j,t}$, can be calculated by $R_{j,t}=\sum_i R_{ij,t}$.

The resulting stocks of ICT and non-ICT capital in the manufacturing sector are described in table 1. Over the period of 1984～1999, the average annual growth rate of the ICT capital stock is about 21.9%, which is 5.3 percentage points higher than 16.6%, the growth rate of non-ICT capital stock. As a result of this, the ratio of the ICT to non-ICT capital stock, i.e., the ICT intensity ratio, has increased from 1.8% in 1984 to 6.7% in 1999.

[Table 1] ICT, non-ICT Capital Stock and Growth Rates in the Manufacturing industry Sector

year	ICT capital stock		Non-ICT capital stock		ICT intensity rates(A/B)(%)
	Size(A), billion won, 1995 constant price	growth rate(%)	Size(B), billion won, 1995 constant price	growth rate(%)	
1984	1,091.63	-	61,121.74	-	1.79
1985	1,281.41	17.39	67,009.35	9.63	1.91
1986	1,507.42	17.64	78,090.02	16.54	1.93
1987	1,782.07	18.22	89,051.05	14.04	2.00
1988	2,121.04	19.02	104,081.60	16.88	2.04
1989	2,544.81	19.98	117,818.01	13.20	2.16
1990	3,080.79	21.06	132,878.69	12.78	2.32
1991	3,792.75	23.11	150,948.70	13.60	2.51
1992	4,732.86	24.79	168,023.24	11.31	2.82
1993	5,971.69	26.18	179,144.65	6.62	3.33
1994	7,604.47	27.34	195,686.80	9.23	3.89
1995	9,759.69	28.34	217,588.96	11.19	4.49
1996	12,042.38	23.39	243,180.80	11.76	4.95
1997	14,600.18	21.24	256,908.33	5.64	5.68
1998	17,616.11	20.66	301,624.83	17.41	5.84
1999	21,331.95	21.09	320,142.90	6.14	6.66

[8] In fact, when we allow a 10% change in the initial stock of ICT capital, the levels of ICT capital in each industry changes 0.1～0.5% in 1990, 0.01～0.02% changes in 1995, and almost zero percent change in 2000.

Ⅲ. THE ECONOMETRIC MODEL

We adopt a restricted cost function where ICT capital is a quasi-fixed input and other traditional inputs such as labor and non-ICT capital are variable inputs. We judge that the treatment of the ICT capital as a quasi-fixed input is a reasonable assumption, because, normally, a certain length of time is required before ICT capital can be used substantially in the production process and because it is difficult to change the level of such stock in the short term. In fact, Sichel(1997) pointed out that the time lags are one of the important factors explaining the productivity paradox of ICT equipment.[9] Furthermore, the most important obstacle in designating the ICT capital as a variable input is the unavailability of accurate market price data for ICT capital input. This also limits the investigation of the precise substitution possibilities between ICT capital and other inputs.

We use a variable cost function of the general form $CV = CV(Q, \mathbf{P_X}, R, T)$, where CV is the minimum expenditure on three variable inputs, Q is the quantity of final output, $\mathbf{P_X}$ is the vector of variable input prices, R is the quantity of quasi-fixed ICT capital input, and T is the index of technology which is a simple time function. For empirical estimation, we specify a translog form for the restricted cost function as given by equation (3):

$$\begin{aligned}\ln CV &= \alpha_0 + \alpha_Q \ln Q + \sum_{i=L,K,M} \alpha_i \ln P_i + \alpha_R \ln R + \alpha_T \cdot T \\ &+ \frac{1}{2}\gamma_{QQ}(\ln Q)^2 + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \ln P_i \ln P_j + \frac{1}{2}\gamma_{RR}(\ln R)^2 + \frac{1}{2}\gamma_{TT} \cdot T^2 \\ &+ \sum_{i=L,K,M}\gamma_{iQ} \ln P_i \ln Q + \sum_{i=L,K,M}\gamma_{iR}\ln P_i \ln R + \sum_{i=L,K,M}\gamma_{iT}\ln P_i \cdot T \\ &+ \gamma_{QR}\ln Q \ln R + \gamma_{QT}\ln Q \cdot T + \gamma_{RT}\ln R \cdot T, \qquad i,j = L,K,M.\end{aligned} \tag{3}$$

where α_S, γ_S are the parameters to be estimated, and without loss of generality, $\gamma_{ij} = \gamma_{ji}$ for $i \neq j$. In the translog specification given by equation (3), linear homogeneity of the restricted cost function with respect to variable input prices implies the following restrictions:

$$\begin{aligned}&\sum_i \alpha_i = 1, \\ &\sum_i \gamma_{iQ} = \sum_i \gamma_{iR} = \sum_i \gamma_{iT} = \sum_i \gamma_{ij} = \sum_j \gamma_{ij} = \sum_i\sum_j \gamma_{ij} = 0, \quad i,j = L,K,M.\end{aligned} \tag{4}$$

The demands for the variable inputs implied by the specification of the cost

---

[9] Six kinds of explanations of the productivity paradox were suggested by Sichel(1997): mismanagement, redistribution, long learning-lags, mismeasurement, offsetting factors, and the small shares of computers in the total capital stock.

function are obtained by using Shephard's Lemma

$$S_L = \alpha_L + \sum_{j=L,K,M} \gamma_{Lj} \ln P_j + \gamma_{LQ} \ln Q + \gamma_{LR} \ln R + \gamma_{LT} \cdot T, \tag{5.1}$$

$$S_K = \alpha_K + \sum_{j=L,K,M} \gamma_{Kj} \ln P_j + \gamma_{KQ} \ln Q + \gamma_{KR} \ln R + \gamma_{KT} \cdot T, \tag{5.2}$$

and

$$S_M = 1 - S_L - S_K$$

where $S_i = P_i X_i / \sum_i P_i X_i$ is the share of i th variable input in variable cost.

We first append an additive error term to the cost function (3) and cost share functions (5.1) and (5.2) and then estimate (3), (5.1) and (5.2) jointly by multivariate nonlinear least squares. The estimation is executed by industry groups using panel data. And in order to avoid autocorrelation across equations, we controlled for autocorrelation in the analysis. Since the cost shares sum to unity, one of the three cost share equations must be dropped to avoid singularity of the variance-covariance matrix. In the current study, we dropped capital from the cost share equations. The cost/ICT-capital elasticity estimate is then obtained from the parametric estimates of the model,

$$E_{CR} = \frac{\partial \ln CV}{\partial \ln R} = \alpha_R + \gamma_{RR} \ln R + \sum_{i=L,K,M} \gamma_{iR} \ln P_i + \gamma_{QR} \ln Q + \gamma_{RT} \cdot T. \tag{6}$$

Uzawa(1962) showed that the (long-run) elasticity of substitution defined by Allen can be computed from the partial derivatives of the total cost function. Similarly, when we allow for the quasi-fixed inputs in the cost function, the short-run elasticity of substitution can be computed from the partial derivatives of restricted cost function as follows:

$$\sigma_{ij}^{SR} = \frac{CV \cdot CV_{ij}}{CV_i \cdot CV_j}, \qquad i, j = L, K, M. \tag{7}$$

where CV is the variable cost function and the subscripts indicate partial derivatives with respect to variable input prices, e.g., $CV_i = \partial CV / \partial P_i$, $CV_{ij} = \partial^2 CV / \partial P_i \partial P_j$. Clearly these short-run or partial equilibrium elasticities of substitution can be calculated straightforwardly using the parameters from the system of estimation equations (3), (5.1) and (5.2).

These short-run elasticities of substitution are valid only for the levels of the fixed inputs at which they are evaluated. Note that, from the short-run elasticities of substitution as specified in equation (7), we cannot obtain any information as to the substitution possibilities between the fixed and variable inputs. However by adopting the approach of Brown and Christensen(1981), which examines the explicit theoretical relationship between the derivatives of the restricted cost function and the total cost function, we can obtain the formulas for the cross elasticities of substitution;

$$\sigma_{ij}=\frac{(1-E_{CR})(S_iS_j+\gamma_{ij})}{S_iS_j}-\frac{(1-E_{CR})(S_jE_{CR}+\gamma_{jR})(S_iE_{CR}+\gamma_{iR})}{(E_{CR}^2-E_{CR}+\gamma_{RR})S_iS_j}, \quad i,j=L,K,M, \quad i\neq j \tag{8}$$

$$\sigma_{iR}=-\frac{(1-E_{CR})(S_iE_{CR}+\gamma_{iR})}{(E_{CR}^2-E_{CR}+\gamma_{RR})S_i}, \quad i=L,K,M \tag{9}$$

where $S_R=\partial\ln CV/\partial\ln R=-P_R\cdot R/CV$ by Hotelling's Lemma.

Now, let us consider the price elasticities of input demand in the production process. The output-constant cross price elasticities of input demand, η_{ij}, are easily derived from the substitution elasticities by the relationship,

$$\eta_{ij}=\frac{\partial\ln X_i}{\partial\ln P_j}=\sigma_{ij}\times\frac{P_jX_j}{CT}, \quad \forall\, i\neq j, \text{ for } i,j=K,L,M,R. \tag{10}$$

where P_jX_j/CT is the cost share of the jth input. Using equations (8), (9), and (10), the own and cross-price elasticities of input demand are given by

$$\eta_{ij}=\frac{d\ln X_i}{d\ln P_j}=\frac{S_iS_j+\gamma_{ij}}{S_i}-\frac{(S_jE_{CR}+\gamma_{jR})(S_iE_{CR}+\gamma_{iR})}{(E_{CR}^2-E_{CR}+\gamma_{RR})S_i}, \quad i,j=,L,K,M, \quad i\neq j. \tag{11}$$

$$\eta_{iR}=\frac{d\ln X_i}{d\ln P_R}=\frac{E_{CR}(S_iE_{CR}+\gamma_{iR})}{(E_{CR}^2-E_{CR}+\gamma_{RR})S_i}, \quad i=L,K,M, \tag{12}$$

$$\eta_{Ri}=\frac{d\ln R}{d\ln P_i}=-\frac{(S_iE_{CR}+\gamma_{iR})}{(E_{CR}^2-E_{CR}+\gamma_{RR})}, \quad i=L,K,M. \tag{13}$$

$$\eta_{RR}=\frac{d\ln R}{d\ln P_R}=-\frac{E_{CR}}{(E_{CR}^2-E_{CR}+\gamma_{RR})}, \tag{14}$$

where η_{ij} =cross-price elasticities of variable input demand, η_{iR} =cross-price elasticities of variable input demand with respect to quasi-fixed input price, η_{Ri} =the cross-price elasticities of quasi-fixed input demand with respect to variable input prices, and η_{RR} =the own price elasticity of quasi-fixed demand.

Ⅳ. DATA

The data set contains an industry breakdown of the annual time series for the Korean manufacturing sector(1984-1999). Output by industry(Q) is measured as gross output at constant prices, obtained from the Report on Mining and Manufacturing Survey(RMMS) of the Korean National Statistics Office. We distinguish between three variable inputs: labor services, intermediate inputs, and capital services. The price of labor services(P_L) is equal to the average hourly wage, which is calculated by $\frac{\text{employees' remuneration}}{\text{no. of workers} \times \text{annual working hours}}$. The employees' remuneration and number of workers are obtained from the RMMS and annual working hours are taken from the Monthly Labor Survey. Using the methodology of Kwak and Park(1998), the intermediate input price(P_M) is constructed as the weighted average of the producer index with weights given by the intermediate input demand ratio as obtained from the I-O table.

Employing the Bureau of Labor Statistics' method of estimating the Jorgenson's service price of capital, the user cost of non-ICT capital(P_K) is defined as $P_{K,t} = q_t(z_t + \delta_t - \dot{q}_t)$, where q_t=price index for a non-ICT capital good at time t, z_t =economy-wide real interest rate, δ_t =depreciation rate for a non-ICT capital good by industries, $\dot{q}_t$ =the rate of nominal capital gain(actually loss) on this asset. Here, as the proxies for q_t and z_t, we use the price index of total capital formation in the National Account and the interest rate on corporate bonds respectively, from the Bank of Korea database. The depreciation rate(δ_t) is endogenously determined in the process of measuring the capital stock.

The non-ICT capital stock(K) is defined as the stock of all durable and reproducible tangible assets which do not have information and communication technology related characteristics. The data on the non-ICT capital stock for each industry are obtained by subtracting the ICT capital estimate from the total capital stock estimate. The (total) capital stocks by industries are constructed from the mixed use of the polynomial-benchmark method and the perpetual inventory method as in the Pyo(1998).

Total variable costs(CV) is defined as the sum of three elements: nominal expenditure on labor, intermediate inputs and the value of flow services of non-ICT capital. Nominal expenditure on labor and intermediate inputs are obtained from the RMMS by the items "employees' remuneration" and "production cost" respectively. The value of the flow services of non-ICT capital is calculated by multiplying the non-ICT capital stock by the implicit price index of total capital formation from the National Account.

[Table 2] Definition and sample statistics of major variables

variable	unit	consumer goods industries	basic material manufacturing industries	assembly and processing industries
cost share of labor	%	15.44 (0.061)	9.67 (0.054)	14.61 (0.029)
cost share of non-ICT capital	%	16.18 (0.045)	20.59 (0.074)	14.99 (0.054)
cost share of intermediate inputs	%	68.37 (0.094)	69.75 (0.095)	70.40 (0.042)
ICT capital	billion won constant price	21.68 (16.53)	30.19 (31.636)	424.35 (479.4)
non-ICT capital	billion won constant price	8933.7 (6228.8)	14681 (11273)	15332 (15830)
output	billion won constant price	16257 (11120)	17525 (12962)	22799 (20650)
employees' remuneration	billion won current price	1736.4 (1518.6)	1373.7 (1178.1)	2413.2 (2072.5)
direct production cost	billion won current price	8601.9 (6668.9)	10837 (8251.5)	13051 (11981)
no. of workers	thousand persons	251.58 (232.85)	145.98 (103.48)	232.64 (135.34)
monthly working hours	hours	220.37 (12.055)	220.28 (12.962)	231.02 (11.96)

Note: The numbers in parentheses are standard errors.

Table 2 shows the definition and sample statistics of major variables. From the fact that the cost share of intermediate input ranges from 68% to 70% for the three industry groups, which far exceeds the labor share or non-ICT capital share, we can confirm the dependency of the Korean manufacturing sector on intermediate inputs. Furthermore, of the three industry groups, consumer goods industries have the largest cost share of labor(15.44%) while basic material manufacturing industries have the largest share of non-ICT capital (20.59%) and the assembly & processing industries have the largest share of intermediate input(70.40%). This implies that the three industry groups i.e., consumer goods industries, basic material manufacturing industries, and assembly & processing industries are labor intensive, non-ICT capital intensive and intermediate input intensive, respectively.

Ⅴ. EMPIRICAL RESULTS

1) Hypothesis tests

The hypothesis tests are conducted by industry groups. We use a likelihood ratio test to test the hypotheses in Table 3. We define the likelihood ratio(λ) as

$\lambda = \frac{L(X:\theta_0)}{L(X:\theta)}$ where the numerator is the likelihood of the sample under the null hypothesis and the denominator is the maximum value of the likelihood. Our test static, $-2\log_e \lambda$, is asymptotically distributed as χ^2 with the degree of freedom equal to the number of restrictions imposed. Either 0.01 or 0.05 level of significance for the individual test is used.

[Table 3] Results of hypothesis tests

Hypothesis	Test Statistics			Critical Value1)	DF
	Consumer Goods	Basic Material Manufacturing	Assembly & Processing		
No cost effect of ICT capital ($\alpha_R = \gamma_{RR} = \gamma_{QR} = \gamma_{RT} = 0,\ \gamma_{iR} = 0,\ i = L, K, M$)	98.37	152.18	55.12	16.81/12.59	6
No technical change ($\alpha_T = \gamma_{TT} = \gamma_{LT} = \gamma_{KT} = \gamma_{QT} = \gamma_{RT} = 0$)	161.89	97.56	74.01	16.81/12.59	6
Hicksian neutrality ($\gamma_{LT} = \gamma_{KT} = 0$)	150.95	7.14	35.67	9.21/5.99	2
Scale neutrality ($\gamma_{QT} = \gamma_{RT} = 0$)	13.75	77.08	15.39	9.21/5.99	2

Note: 1) The left figure is the critical value for the 0.01 significance level and the right figure is for the 0.05 significance level.

As shown in Table 3, the null hypothesis that 'there are no cost effects of ICT capital' is rejected at the 0.01 significance level for all three industry groups. This implies that the ICT capital must likely affect the variable costs in the manufacturing sector. Similarly the null hypothesis that 'there is no technical change' is also rejected for all three industry groups. Hicksian neutrality regarding technical change is rejected both in the assembly & processing industries and in the consumer goods industries at the 0.01 significance level but is not rejected in the basic material manufacturing industries. Scale neutrality regarding technical change is rejected at the 0.01 significance level in for all three industry groups.

2) The estimation of variable cost function

The parameter estimates are reported in table 4 with their estimated standard errors. The estimations were conducted separately for the industry groups. All variables entering in log form are normalized such that the values of their sample means are equal to unity. For each industry group, 15~22 of the 28 parameters are statistically significant at the 0.01 level. The R^2 statistics are 0.997, 0.990, and 0.999 for consumer goods, basic material manufacturing, and assembly & processing industries, respectively. This shows that the cost function fits the data very well. The regularity conditions for the cost function being nondecreasing and concave in the prices of variable factors and nondecreasing and convex in the level of fixed factors are satisfied for most sample points, except for the concavity condition which is not satisfied for the sample points where the estimated capital share is quite small.

[Table 4] Parameter Estimates

Parameter	Consumer Goods	Basic Material Manufacturing	Assembly & Processing
α_0	-1.400(0.665)[b]	-0.526(0.156)[a]	0.230(0.075)[a]
α_Q	0.626(0.080)[a]	1.153(0.071)[a]	0.824(0.061)[a]
α_L	0.426(0.065)[a]	0.342(0.053)[a]	0.146(0.009)[a]
α_K	0.112(0.061)	0.432(0.069)[a]	0.148(0.014)[a]
α_M	0.462(0.073)[a]	0.226(0.067)[a]	0.706(0.012)[a]
α_R	-0.053(0.104)	-0.364(0.144)[b]	-0.568(0.137)[a]
α_T	0.144(0.318)	0.048(0.230)	0.893(0.215)[a]
γ_{QQ}	0.148(0.067)[b]	-0.191(0.123)	0.082(0.050)
γ_{LL}	0.096(0.018)[a]	-0.022(0.017)	0.103(0.011)[a]
γ_{KK}	0.143(0.016)[a]	0.182(0.022)[a]	0.211(0.038)[a]
γ_{MM}	0.110(0.027)[a]	-0.051(0.032)	0.194(0.026)[a]
γ_{RR}	-0.306(0.163)	-0.701(0.125)[a]	-0.053(0.062)
γ_{TT}	0.569(0.443)	-1.023(0.525)[b]	-0.309(0.145)[b]
γ_{LK}	-0.064(0.014)[a]	-0.105(0.015)[a]	-0.060(0.013)[a]
γ_{LM}	-0.032(0.019)	0.127(0.020)[a]	-0.043(0.011)[a]
γ_{LQ}	0.016(0.010)	-0.037(0.018)[b]	-0.050(0.006)[a]
γ_{LR}	0.146(0.015)[a]	0.017(0.017)	0.017(0.005)[a]
γ_{LT}	-0.319(0.026)[a]	0.025(0.032)	-0.063(0.013)[a]
γ_{KM}	-0.079(0.017)[a]	-0.077(0.021)[a]	-0.151(0.029)[a]
γ_{KQ}	-0.016(0.009)	-0.084(0.017)[a]	0.017(0.015)
γ_{KR}	-0.014(0.015)	0.087(0.016)[a]	-0.105E-02(0.016)
γ_{KT}	0.106(0.024)[a]	0.067(0.026)[b]	-0.450E-02(0.021)
γ_{MQ}	0.473E-03(0.012)	0.121(0.026)[a]	0.033(0.012)[b]
γ_{MR}	-0.132(0.019)[a]	-0.104(0.025)[a]	-0.016(0.013)
γ_{MT}	0.214(0.031)[a]	-0.092(0.067)	0.068(0.018)[a]
γ_{QR}	0.178(0.096)	0.451(0.102)[a]	-0.128(0.051)[a]
γ_{QT}	-0.544(0.147)[a]	-0.930(0.149)[a]	-0.014(0.057)
γ_{RT}	0.202(0.241)	1.071(0.251)[a]	0.272(0.086)[a]
R^2	0.997	0.990	0.999

Note; The numbers in parentheses are standard errors.
a: significant at the 0.01 level.
b: significant at the 0.05 level.

From the characteristics of the translog cost function, γ_{iT} $(i = L, K, M)$ represents biases of technical change. The signs for γ_{iT} in table 4 exhibit an interesting pattern. Of the estimated parameters of γ_{iT} which are statistically significant, the negative γ_{LT} and positive γ_{MT} values for both the consumer goods industries and assembly & processing industries indicate that there have been labor saving and intermediate input using technical change in these industries. Particularly, the positive γ_{KT} value for the consumer goods industries indicates that there has been non-ICT capital using technical change in this industry group. For the basic material manufacturing industries, however, the estimated parameters of γ_{iT} are not statistically significant except for γ_{KT} which is positive and significant at the 0.05 level.

It is somewhat interesting that the technical change played the role of reducing the cost share of labor and increasing the share of intermediate inputs in both the consumer goods industries and the assembly & processing industries during the period of rapid increase in labor service price since the 80's. In the basic material manufacturing industries, on the other hand, we obtained technical change to be non-ICT capital using or neutral.

We use the Allen elasticities of substitution(AES) to evaluate the effect of change in the relative price on the input structure. Estimates of Allen elasticities of substitution between pairs of inputs are shown in table 5. Estimates of the elasticities of substitution between labor and non-ICT capital(σ_{LK}) exhibit a clear sign pattern across industry groups, with both consumer goods industries and assembly & processing industries showing negative estimates, thus indicating complementarity between these inputs. The basic material manufacturing industries, however, exhibit only slightly positive estimates of σ_{LK}, hence indicating poor substitutability between these inputs. Especially the estimates of σ_{LK} are significantly larger than 2 in absolute magnitude in all of the assembly & processing industries.

The estimates of σ_{LM} exhibit positive sign in all the industries, which implies that most firms in the manufacturing industry substitute labor for intermediate inputs. The estimates of σ_{KM} do not exhibit a clear pattern across industries except for the assembly & processing industries where a complementary relationship between non-ICT capital and intermediate input is found.

The estimated elasticities of substitution between ICT capital(R) and other variable inputs are presented in the last 3 columns of table 5. In 11 of the 13 Korean manufacturing industries the positive signs of the estimated σ_{LR} imply substitutability between ICT capital and labor, leading to the conclusion that higher labor prices will tend to accelerate ICT investment and hence growth in this industry group. In particular, the consumer goods industries except printing industry show strong substitutability between ICT capital and labor.

[Table 5] Allen Elasticities of Substitution

	σ_{LK}	σ_{LM}	σ_{KM}	σ_{LR}	σ_{KR}	σ_{MR}
Food and Beverage	-0.825	0.352	0.145	1.500	-1.567	-2.640
Textile and Leather	-0.701	0.496	-0.354	1.250	-0.492	-0.975
Paper and Wood	-0.907	0.491	0.024	1.611	-0.147	-0.452
Printing	-0.162	1.019	-0.698	0.409	0.926	1.698
Chemicals	0.324	2.570	0.228	0.477	0.529	0.303
Petroleum	0.205	1.112	0.181	0.219	0.345	0.132
Nonmetallic Minerals	0.424	2.904	0.086	-0.229	0.116	-1.432
Primary Metals	0.089	2.801	-0.340	0.247	0.510	0.060
Metal Fabricating	0.471	6.456	-0.633	-0.467	-0.119	-3.565
General Machinery	-3.695	0.384	-1.173	0.752	1.107	1.142
Precision Instruments	-2.012	0.644	-1.161	0.763	1.271	1.351
Transportation Equipment	-2.551	0.378	-1.035	0.848	1.074	1.106
Electronics	-3.086	0.217	-0.890	0.821	1.062	1.090
Weighted Average[1]						
Total Manufacturing	-1.229	1.306	-0.432	0.727	0.346	-0.091
Consumer Goods	-0.736	0.481	-0.150	1.330	-0.723	-1.301
Basic Material Manufacturing	0.280	2.944	-0.037	0.192	0.374	-0.447
Assembly & Processing	-3.031	0.321	-1.013	0.812	1.082	1.115

Note: 1)Weighted by the value of output.

The two substitution elasticities with regard to ICT capital (σ_{KR}, σ_{MR}) exhibit very similar patterns across industry groups. Both the estimates of σ_{KR} and σ_{MR} exhibit negative signs for the consumer goods industries excluding printing industry, indicating complementarity between non-ICT capital and ICT capital on the one hand and between intermediate input and ICT capital on the other hand. For the assembly & processing industries, σ_{KR} and σ_{MR} are estimated to be positive, thus indicating substitutability between those inputs. However, the absolute magnitude of σ_{MR} are always larger than these of σ_{KR} in both consumer goods industries and assembly & processing industries, which suggests that the relationship between ICT capital and intermediate inputs is closer than that between ICT capital and non-ICT capital in these two industry groups.

For the basic material industries except nonmetallic minerals and metal fabricating, the estimates of σ_{KR} and σ_{MR} are positive or close to zero, indicating weak substitutability between ICT capital and these two variable inputs.

3) The cost effects of ICT-capital

Estimates of the cost/ICT-capital elasticities(E_{CR}) are shown in Table 6. These elasticities are presented by year instead of as average values over certain periods, since the estimated measures vary smoothly over time.

In most industries, the estimated cost/ICT-capital elasticities show negative value as one might expect, but the magnitude, time trend and statistical significance vary across the industries. Of the 10 industries which belong to consumer goods industries and basic material industries, only 2 industries - printing and metal fabricating - show negative and statistically significant cost/ICT-capital elasticity for the entire time period, implying that the ICT-capital has cost saving effects in these 2 industries. Particularly the metal fabricating industry shows relatively high absolute value of cost/ICT-capital elasticities. Although the remaining industries in these industry groups exhibit the negative cost/ICT-capital elasticities, these are not supported statistically.

[Table 6] Estimates of cost/ICT-capital Elasticities(E_{CR})

	1984	1989	1994	1999
Food and Beverage	0.021(0.140)	-0.154(0.105)	-0.108(0.123)	-0.098(0.144)
Textile and Leather	-0.016(0.140)	-0.011(0.114)	-0.023(0.129)	-0.095(0.145)
Paper and Wood	-0.020(0.142)	0.046(0.150)	0.044(0.160)	0.045(0.171)
Printing	-0.187(0.171)	-0.267(0.128)[b]	-0.274(0.134)[b]	-0.294(0.162)[b]
Chemicals	-0.631(0.176)[a]	-0.378(0.186)[b]	-0.232(0.187)	-0.089(0.192)
Petroleum	0.005(0.106)	0.505(0.114)	0.774(0.110)	0.393(0.121)
Nonmetallic Minerals	-0.388(0.094)[a]	-0.070(0.069)	0.199(0.054)	0.360(0.084)
Primary Metals	-0.743(0.150)[a]	-0.306(0.121)[a]	-0.153(0.128)	-0.144(0.163)
Metal Fabricating	-0.756(0.098)[a]	-0.332(0.075)[a]	-0.382(0.086)[a]	-0.233(0.112)[b]
General Machinery	-0.528(0.071)[a]	-0.495(0.090)[a]	-0.474(0.115)[a]	-0.300(0.124)[a]
Precision Instruments	-0.192(0.080)[b]	-0.212(0.062)[a]	-0.146(0.071)b	-0.134(0.093)
Transportation Equipment	-0.622(0.116)[a]	-0.584(0.123)[a]	-0.539(0.137)[a]	-0.391(0.143)[a]
Electronics	-0.478(0.153)[a]	-0.628(0.155)[a]	-0.630(0.161)[a]	-0.535(0.166)[a]
Weighted Average				
Total Manufacturing	-0.330	-0.264	-0.243	-0.218
Consumer Goods	-0.013	-0.069	-0.062	-0.091
Basic Material Manufacturing	-0.538	-0.191	-0.055	-0.022
Assembly & Processing	-0.521	-0.574	-0.551	-0.419

Note; Weighted average are weighted by the value of output.
The numbers in parentheses are standard errors.
a: significant at the 0.01 level.
b: significant at the 0.05 level.

All the industries belonging to assembly & processing industries(general machinery, precision instruments, transportation equipment, electronics) show negative and statistically significant cost/ICT-capital elasticities. The weighted average of these values fluctuates between -0.41 and -0.57 for 1984～1999, implying that there have been cost saving benefits by accumulating the ICT capital at least in the assembly & processing industries.

As Morrison(1997) pointed out, an important insight into the productive effect of ICT capital can be obtained by considering the variable input-specific cost effects of ICT investment, generated through the individual variable input demand. In order to capture the input-specific cost effects of ICT capital generated through the individual variable input demand, we introduce the elasticity of input demand with respect to change in ICT capital, ψ_{iR}. And ψ_{iR} can be derived from equations (12), (13) and (14) as follows,

$$\psi_{iR} = \frac{\partial \ln X_i}{\partial \ln R} = \frac{\eta_{iR}}{\eta_{RR}} = \frac{S_i E_{CR} + \gamma_{iR}}{S_i} \, . \tag{15}$$

In Table 7, the estimated elasticities of input demands with respect to ICT-capital, i.e., ψ_{LR}, ψ_{KR}, and ψ_{MR}, are reported for 1984, 1989, 1994 and 1999. As shown in the table, the weighted average of the estimates of ψ_{KR} in the total manufacturing sector ranges from -0.034 to -0.351 while the weighted average of ψ_{MR} ranges from -0.442 to -0.571, indicating that the absolute values for ψ_{MR} are significantly higher than those for ψ_{KR}. Although increases in ICT-capital tend to reduce the demand for non-ICT capital and the demand for intermediate inputs, the response to the change in ICT-capital is more sensitive in the demand for intermediate inputs than the response in the demand for non-ICT capital. This implies that increases in ICT related investment save intermediate inputs use in the production process, which tends to contradict the generally held perception that introducing more ICT equipment is conducive to "outsourcing".

For the estimates of ψ_{LR} the sign changes from negative during 1984~94 to positive in 1999, indicating a switch from substitutability to complementarity as the response of labor to the change of ICT-capital. These results are based on the weighted average in the total manufacturing sector. The sign or magnitude of the estimated ψ_{iR} shows obvious divergence across individual industries or industry groups.

Comparing the weighted average between industry groups, we find that the estimated sign of ψ_{LR} is different between consumer goods industries($\psi_{LR}>0$) and assembly & processing industries($\psi_{LR}<0$). This implies that, as a response to the increase of ICT capital, the labor demand increased(complementarity) in the consumer goods industries whereas it decreased(substitutability) in the assembly & processing industries. In the basic material industries, ψ_{LR} changes from negative values over the period 1984~94 to the positive value in 1999.

The estimates of ψ_{KR} exhibit negative signs in the industries belonging to the consumer goods industries or assembly & processing industries. This implies that the increasing availability of ICT capital represses the marginal product of non-ICT equipment, motivating substitution from more "traditional" equipment and toward ICT equipment. As a result, this should accelerate the change in the composition of capital toward ICT equipment, i.e., increase the ICT intensity ratio in each industry.

[Table 7] Elasticities of Input Demand with respect to ICT-Capital

	ϕ_{LR}				ϕ_{KR}				ϕ_{MR}			
	1984	1989	1994	1999	1984	1989	1994	1999	1984	1989	1994	1999
Food and Beverage	0.447	0.187	0.227	0.286	-0.122	-0.287	-0.226	-0.214	-0.212	-0.433	-0.399	-0.356
Textile and Leather	0.312	0.340	0.407	0.322	-0.201	-0.151	-0.090	-0.201	-0.288	-0.281	-0.240	-0.347
Paper and Wood	0.491	0.611	0.599	0.647	-0.107	-0.059	-0.051	-0.054	-0.189	-0.167	-0.178	-0.166
Printing	0.202	0.302	0.175	0.160	-0.284	-0.243	-0.319	-0.365	-0.440	-0.409	-0.523	-0.565
Chemicals	-0.587	-0.298	-0.030	0.339	-0.416	-0.154	0.107	0.474	-1.130	-0.779	-0.497	-0.268
Petroleum	0.053	0.556	0.830	0.441	0.302	0.795	1.043	0.599	-0.291	0.220	0.492	-0.071
Nonmetallic Minerals	-0.346	-0.023	0.249	0.403	0.014	0.148	0.398	0.536	-0.928	-0.515	-0.275	-0.568
Primary Metals	-0.699	-0.257	-0.100	0.070	-0.514	-0.078	0.047	0.200	-1.197	-0.698	-0.582	-0.749
Metal Fabricating	-0.715	-0.336	-0.221	-0.189	-0.553	-0.185	-0.095	-0.079	-1.439	-0.964	-0.935	-3.489
General Machinery	-0.424	-0.376	-0.339	-0.139	-0.537	-0.503	-0.481	-0.308	-0.549	-0.517	-0.496	-0.319
Precision Instruments	-0.096	-0.124	-0.053	-0.021	-0.204	-0.222	-0.140	-0.020	-0.213	-0.234	-0.156	-0.034
Transportation Equipment	-0.562	-0.477	-0.430	-0.266	-0.672	-0.592	-0.546	-0.401	-0.683	-0.605	-0.561	-0.412
Electronics	-0.327	-0.483	-0.482	-0.377	-0.491	-0.636	-0.636	-0.542	-0.498	-0.649	-0.651	-0.556
Weighted Average												
Total Manufacturing	-0.107	-0.083	-0.025	0.041	-0.351	-0.241	-0.134	-0.034	-0.571	-0.509	-0.442	-0.508
Consumer Goods	0.348	0.334	0.370	0.331	-0.173	-0.186	-0.140	-0.185	-0.249	-0.326	-0.301	-0.334
Basic Material Manufacturing	-0.572	-0.242	-0.025	0.167	-0.331	0.008	0.228	0.388	-0.863	-0.603	-0.406	-0.689
Assembly & Processing	-0.397	-0.439	-0.406	-0.258	-0.559	-0.584	-0.559	-0.431	-0.571	-0.596	-0.569	-0.435

The estimates of ϕ_{MR} are negative in most industries except for petroleum, implying substitutability between intermediate inputs and non-ICT capital. Furthermore, in the consumer goods industry the weighted average of ϕ_{MR} is increasing in absolute magnitude over time, suggesting that the impact of ICT on intermediate input demand has strengthened over time. In the assembly &

processing industries on the other hand, this value is decreasing in absolute magnitude over time, suggesting that the impact of ICT on intermediate input demand has weakened over time.

From the above discussion, the following implications can be derived relating cost reducing impacts of ICT-related investment. One important observation is that the industries where the cost reducing effects of ICT capital are supported statistically - all industries in the assembly & processing industries, metal fabricating in the basic material industries, and printing industry in the consumer goods industries - substitute non-ICT capital or intermediate input for ICT capital. In the mentioned industries, the estimated signs of ψ_{MR} or ψ_{KR} are negative, implying that an increase in the ICT capital reduces the demand for intermediate inputs or demand for non-ICT capital. In other words, an increase in the ICT capital stock(incorporating the R&D activities embodied in the ICT related investment good) contributes to the efficiency of the corresponding industry by reducing the demand for non-ICT capital or demand for intermediate input.

Ⅵ. CONCLUDING REMARKS

Our purpose in this paper has been to measure the ICT capital stock using the I-O tables by industries and to examine empirically the cost reducing impacts of ICT capital from 1984 through 1999 by estimating the translog variable cost function. From our analysis, we could derive several major results.

First, during the sample periods of 1984-1999, there have been large ICT investments in the Korean manufacturing industries. As a result, the ratio of ICT to non-ICT capital (ICT intensity) has increased from 1.8% in 1984 to 6.7% in 1999. However, despite ICT investments having increased, the cost reducing effects of ICT capital could not be found for all the industries. From the estimates of the cost/ICT-capital elasticities by industries, the cost-reducing effects of ICT-capital are supported statistically for 6 industries : for all 4 industries in the assembly & processing industries, for metal fabricating in the basic material industries, and for the printing industry in the consumer goods industries.

Additionally, an important insight into the productivity effect of ICT capital could be derived from the variable input-specific cost effects of ICT capital investment, generated through the individual variable input demand. In the total manufacturing sector, the elasticity of demand for labor with regard to ICT capital(ψ_{LR}) changed from negative during 1984～94 to positive in 1999, indicating a switch from substitutability to complementarity as the response of labor to the change of ICT capital. This implies that the generally held belief that ICT capital substitutes for labor cannot be applied for the Korean manufacturing industry at least since the late 90s.

However, in the industries where the cost-reducing effects of ICT capital are supported statistically, the estimated signs of ψ_{KR} and ψ_{MR} are negative, implying that an increase in the ICT capital reduces the demand for intermediate inputs and the demand for non-ICT capital. This suggests that an increase in the ICT capital stock, incorporating the R&D activities embodied in the ICT related investment good, is contributing to the efficiency of the corresponding industry by reducing the demand for non-ICT capital and demand for intermediate input.

This paper contributes to the literature as a trial research on the cost effects of ICT capital and on the input substitution possibilities between ICT capital and other reproducible inputs in the Korean economy. Yet, there is still need for future research on these issues. The first priority would be to include the service sector in the analysis. Although the ICT capital stock of the service sector is likely to be much smaller than that of the manufacturing sector, its impact on productivity or the relationship with other reproducible inputs may be quite different. In fact, Lee(2001) reports that the ICT-intensity factor's positive impact on the productivity growth is more prominent in the service sector than in the manufacturing sector.

Finally, the data quality gives rise to some concerns. Since government statistics on ICT investment or ICT capital stock by industries were not available, we had to construct these data by resorting to I-O tables. However, we faced several problems in the measuring process, for example, the problem of the hedonic price index which incorporates the quality changes of ICT equipment and treated them with a simple assumption. Accordingly, we remember the ICT-related data such as ICT investment or ICT capital stock by industries used here are still blunt. Thus future improvements in the quality of the data set would be desirable to make the analysis more accurate and efficient.

REFERENCES

Bank of Korea (2000), "The Impact of Information and Communication Technology Industry on the Productivity of Korean Industries," unpublished manuscript(in Korean).

Berndit, E.R. and T.W. Malone (1995), "Information Technology and the Productivity Paradox: Getting the Questions Right," *Economics of Innovation and New Technology*, Vol. 3, pp.177-182.

Berndit, E.R., Morrison, C. and L. Rosenblum (1992), "High-tech Capital Formation and Labor Compositions in U.S. Manufacturing Industries: An Exploratory Analysis," NBER Working Paper, 4010.

Brown, R.S. and L.R. Christensen (1981), "Estimating Elasticities of Substitution in a Model of Partial Static Equilibrium: An Application to U.S. Agriculture, 1947 to 1974," in E.R. Berndt and B.C. Field(eds.), *Modeling and Measuring Natural Resource Substitution* (Cambridge, MA: MIT Press, 1981).

Brynjolfsson, E. and S. Yang (1996), "Information Technology and Productivity: A Review of the Literature," *Advances in Computers*, Vol. 43, pp.179-214.

Brynjolfsson, E. and E.L. Hitt(1995), "Information Technology as a Factor of Production: The Role of Differences among Firms," *Economics of Innovation and New Technology*, Vol. 3, pp.183-199.

Christensen, L.R. and D.W. Jorgenson(1969), "The Measurement of U.S. Real Capital Input, 1929-1967," *Review of Income and Wealth*, Vol. 15, No. 4, pp.293-320.

Gordon, R.J. (2000), "Does the "New Economy" Measure up to the Great Inventions of the Past?," *Journal of Economic Perspective*, Vol. 14, pp.49-74.

Halvorsen R. and T.S. Smith (1986), "Substitution Possibilities for Unpriced Natural Resources: Restricted Cost Functions for the Canadian Metal Mining Industry," *Review of Economics and Statistics*, Vol. 68, pp.398-405.

Huggett, M. and S. Ospina (2001), "Does Productivity Growth Fall after the Adoption of New Technology?," *Journal of Monetary Economics*, Vol. 48, pp.173-195.

Jorgenson, D.W. and K.J. Stiroh (2000), "Raising the Speed Limit: U.S. Economic Growth in the Information Age," *Brookings Papers on Economic Activity*, No. 1, pp.125-235.

Kang, I.H. and J.K. Song (1999), "The Investment on Information Technology and the Productivity of Banks in Korea," *KYONGJEHAKYONGU*, Vol. 47 No. 3, pp.65-98(in Korean).

Kwack, M.S. and S.R. Park (1998), "Measuring the Price Collusion Behaviour of the Korean Manufacturing," *Kukje Kyungje Yongu*, Vol. 4, No. 1, pp.153-179(in Korean).

Kim S.J. (2003), "The Information Technology and its Impact on Economic

Growth and Productivity," *International Economic Journal*, Vol. 17, pp.55-75.

Kim W.J. and J.D. Lee (2001), "The Sectoral Estimation and Analysis of Information and Telecommunication Capital Stock in the Korean Industry," *Productivity Review*, Vol. 15, No. 1, pp.229-248(in Korean).

Lee, K.D. (2000), "The Adoption of Information Technology and Performance of Firms in the Korean Textile Industry," *Kukje Kyungje Yongu*, Vol. 6, No. 2, pp.145-174(in Korean).

Lee, K.D. (2001), "An Analysis on the Productivity Effects of the Information and Communication Technology Investment in Korean Industries," *Kukje Kyungje Yongu*, Vol. 7, No. 2, pp.163-197(in Korean).

Lichtenberg, F.R. (1995), "The Output Contributions of Computer Equipment and Personnel: A Firm-level Analysis," *Economics of Innovation and New Technology*, Vol. 3, pp.201-217.

Morrison, C.J. (1988), "Quasi-fixed Inputs in U.S. and Japanese Manufacturing: A Generalized Leontief Restricted Cost Function Approach," *Review of Economics and Statistics*, Vol. 70, pp.275-287.

Morrison, C.J. (1997), "Assessing the Productivity of Information Technology Equipment in the U.S. Manufacturing Industries," *Review of Economics and Statistics*, Vol. 70, pp.471-481.

Schreyer, P. (2000), "The Contribution of Information and Communication Technology to Output Growth : A Study of the G7 Countries," OECD STI Working Paper.

Shapiro, C. and H.R. Varian (1999), *Information Rules : A Strategic Guide to the Network Economy*, Harvard Business School Press.

Shin, I.S., Kim, H.K. and J.K. Song (1998), "The Use of Information Technology and Performance of Firm," *KYONGJEHAKYONGU*, Vol. 46, No. 3, pp.253-278(in Korean).

Sichel, D.E. (1997), *The Computer Revolution: An Economic Perspective*, The Brookings Institution.

Oliner, S.D. and D.E. Sichel (1994), "Computers and Output Growth Revisited: How Big Is the Puzzle," *Brookings Papers on Economic Activity*, No. 2, pp.272-334.

Oliner, S.D. and D.E. Sichel (2000), "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?," *Journal of Economic Perspective*, Vol. 14.

Pyo, H.K. (1998), *Estimates of Fixed Reproducible Tangible Assets in the Republic of Korea*, 1954～1996, Korea Institute of Public Finance.

Uzawa, H. (1962), "Production Functions with Constant Elasticities of Substitution," *The Review of Economic Studies*, Vol. 29, pp.291-299.

<Appendix A> The Composition of ICT sector and Matching with the I-O Table

Categories	Sub-category and items	I-O table (1985)	I-O table (1990)	I-O table (1995)
Manufacture of information and telecomm. equip.	**<Information Equipment>** Computer and peripheral equipment	282	265~266	269
	<Parts> Transformers; Electronic coils, transformer and other inductors; Other electric motors, generators and transformers; Electrical apparatus used in distribution system; Boards for electric control or distribution; Electronic valves and tubes; Printed circuit boards; Electronic capacitors; Electronic resistors, Liquid crystal displays; Other electronic valves, tubes and electronic components	272 3.9% of 273 274, 284 286~288	269~270 286 290~293	248~249 255~256 259~262
	<Semiconductors> Diodes, transistors and similar semi-conductor devices; Electronic integrated circuits	285	287~289	257~258
	<Communication Equipment> Insulated wires and cables; Optical fiber cables made-up individually sheathed fibers; Line telecommunication equipment; Communication apparatuses without any line connection and radio or TV broadcasting apparatuses; TV and radio receivers; Instruments and appliances for radio navigating and measuring; Communication satellite,	275 289~290	272 284~285	251 267~268
Information and telecomm. services	**<Communication Services>** Leased line services; Wired telephone and other telecommunications; Mobile telephone services; Cellular telephone services; Telecommunications resellers; Value added communication; Other telecommunications n.e.c.	362~363	360	348~349
	<Broadcasting Services> Radio broadcasting; TV broadcasting; Cable networks; Cable and other program distribution; Broadcast via satellite; Broadcasting programmes production	393	392~393	350~351
S/W related activities	**<SW and Computer Related Services>** Computer system design and consultancy; Game software publishing; Other S/W consultancy and supply; Data processing; Computer facilities management services; DB activities and on-line information provision services; Other computer activities; Maintenance and repair services of electric and precision equipment	11% of 372	371	363