Measuring Economic Externalities of IT and R&D

Myung-Hwan Rim, Sang-Sup Cho, and Choon-Geol Moon

We measure and compare externalities of IT and R&D capital stocks in different Korean industry sectors using inter-industry input-output tables of 1985, 1990, 1995 and 2000. We also compute the multiplier effects that relate to the directions of future economic effects. The key findings are as follows. First, we observed continuous capital deepening in all nine industries over the period of 1985 to 2000. Second, the backward multipliers of IT capital were the highest in the manufacturing industry. As for inter-industry externalities, the indirect backward multipliers, which exclude intra-industry backward multiplier effects within the industry, were also the highest in the manufacturing industry. Third, the forward multiplier effects of IT capital stock were the most substantial in the construction industry during the 1980s and in the manufacturing industry thereafter. Finally, using the transition multiplier matrix reflecting the backward effects of the two capitals in the past, the economic backward effects, especially the external economic effects, are predicted to increase through 2010 among all industries. The above findings suggest that, in order to maximize the forward and backward effects of the ever-increasing IT capital, we need to formulate an industry policy reducing the cost of capital accumulation in the manufacturing industry through improvement in productivity of the IT industry.

Keywords: IT, R&D, capital stock, externality effect, input-output analysis, inter-industry analysis.

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I. Introduction

The debate on how much and how profoundly IT capital and IT technology in general contribute to a national economy is closely related and is in fact more or less equivalent to the debate on the *raison d'etre* of the "New Economy," an economic paradigm launched in the 1990s. As has been voiced by Solow [1] in his much-quoted sentence, "We see computers everywhere except in the productivity statistics," there is a rising skepticism about the economic benefit of massive investments in IT that took place during the two decades between 1970 and 1990. Meanwhile, speaking from the opposite camp, Greenspan [2] observed that the US economy is currently undergoing major shifts in all its segments, and these shifts, rather than being a part of economic cycles or transitory phenomena, or being caused by statistical errors, are fundamental in nature. There are also studies arguing that the IT industry, or IT, is an important engine for the productivity increase in the US economy. The work by Oliner and Sichel [3] is one of the most emphatic studies in support of such a view. Recently Colecchia and Schreyer [4] compared the impact of information and communication technology capital accumulation on output growth in Organisation for Economic Co-operation and Development (OECD) countries.

On the other hand, from an academic viewpoint, the contribution of R&D investment to a national economy has been continuously under discussion since Romer [5]. Agion and Howitt [6] and Grossman and Helpman [7] demonstrated theoretically that the R&D capital could play an important role in national economic development. However, empirical research has produced mixed results. Jones [8] asserted that the long-term data on the R&D capital accumulation by the advanced countries does not support the theory of endogenous growth based on R&D. On the contrary, Coe and Helpman [9] showed that the accumulation of R&D capital has positively contributed to a productivity enhancement of the OECD countries, taking into account the spillover effects, the unique characteristics of R&D capital.

Evaluating the role of IT capital and R&D capital in an analytical framework that only deals with economic gains and losses in a handful of industries is too partial to produce an objective and balanced assessment of these effects. For an accurate evaluation of the role of these capitals in an economy, we must adopt a general equilibrium approach, measuring not only its intra-industry effect but also inter-industry effect.

Looking at the Korean experience, the share of the IT industry in Korea's national economy has been fast increasing, and this industry has been playing an important role as an infrastructure to other industries, paving a way for Korea to move toward an information society. To quantify the underlying process of this observation, among many others we measure inter-industry spillovers of IT capital stock. We also quantify linkage effects of R&D capital using long-term data, proposing policy suggestions for bolstering economic growth and enhancing innovation capabilities. In sum, using Korean input-output tables, we measure inter-industry linkage coefficients and multipliers, and then draw suggestions for formulating a policy for a national growth drive.

There have been numerous Korean studies on economic inter-sectoral linkages between sectors in the IT industry, including Rim [10] and Choi, Jeong and Hong [11]. However, there are few studies to date on technological inter-industry linkages between industries of the Korean economy as a whole. Cho, Jeong and Jang [12] focused on economic effects of R&D expenditures on economic growth at the country level in examining the empirical validity of the R&D-based growth theory, but they did not attempt to analyze the inter-industry linking effect in a specific country. That is, the central thesis of new growth theories spawned ever since the seminal works of Romer [5] and Lucas [13], which argue for the critical importance of accounting for inter-industry and inter-company technological linkages or spillovers, has not yet been empirically tested for the Korean economic reality. Using firm-level panel data, Lee and Hwang [14] investigated the determinants of corporate R&D investment in the IT industry.

Notable existing works with a similar set of research objectives include Mun and Nadiri [15] and Park and Jeon [16]. Mun and Nadiri [15] measure externalities of IT capital in 42 US industries using inter-industry input-output tables from the years 1984 to 2000. They found that in 32 industries, the backward spillover effect was superior to the forward spillover effect. The levels of the backward spillovers appeared to be more or less similar in size across industries, whereas the forward spillovers showed significant disparity, being much more significant in service industries than in manufacturing industries. In a similar vein, Park and Jeon [16] compared the technological spillovers and linkage structures in manufacturing and service industries, focusing on knowledge-based sectors.

In this study, we reclassify the industries in the input-output tables into nine aggregate industries and we measure externalities of IT capital stock in and across these industries using the concept of the research and development multiplier proposed by Dietzenbacher and Los [17]. For the data on IT capital stock, we use the data compiled by Cho and Jeong [18], who calculated estimated amounts of IT capital stocks in nine industries using Korean inter-industry input-output tables from the years 1985 to 2000. For the data on R&D capital, we use the data compiled by Seo and Jeong [19]. We then analyze the nine aggregate industries for the data years (1985, 1990, 1995 and 2000) of Korean Input-Output Tables by the Bank of Korea [20] using the concept of the research and development multiplier by Dietzenbacher and Los [17]. We look at both backward R&D multipliers and forward R&D multipliers. In addition, by extending the trends of the multiplier matrix measuring direct and external economic effects, we forecast the next ten years and draw policy implications.

An increase in the final demands in industries with high backward multipliers of IT and R&D capital stocks will boost the IT industry as well as the R&D intensive industry, resulting in positive output increases in other industries. Likewise, cost savings in industries with high forward multipliers thanks to the accumulation of IT and R&D capital stocks will contribute to stronger price competitiveness of final products in their customer industries. Hence, by quantifying the sizes of these effects, we can naturally identify core industries of strategic policy support, from the perspectives of the accumulation of IT and R&D capital stocks.

The rest of this paper is organized as follows: Section II presents a brief description of key analytic concepts in this paper. Section III first describes the data used in the study and then analyzes inter-industry externalities of IT capital in nine Korean industries. Finally, the industry linkage effects of two capitals in the national economy are compared. Section IV concludes with a brief summary of the key results and their implications.

II. Methodology

1. Measuring Direct and External Economic Effects

In this section, we will describe a method to measure the externalities of IT capital in nine industries based on the concept of research and development multipliers proposed by

Dietzenbacher and Los [17]. In order to define multipliers for the amounts of IT and R&D capitals in detail, we use the annual inter-industry transaction in input-output tables. The following section describes the steps of measurement briefly.

The matrix Z of intermediate input transactions is defined as

$$Z \equiv \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & \cdot & \cdots & x_{2n} \\ \cdot & \cdot & \cdots & \cdot \\ x_{n1} & x_{n2} & \cdots & x_{nn} \end{bmatrix}, \quad (1)$$

where x denotes the gross output vector; the final demand or final output vector (f) may be expressed in terms of private and governmental consumptions (c), total fixed asset investment (i), exports (e) and competing goods imports (m).

$$f \equiv c + i + e \quad (2)$$

If we denote the value-added vector as v, the relationship between gross output, intermediate input demand, and final demand, and that between gross outputs, intermediate input, and value added may be expressed in the following simplified representations (where **1** stands for a vector composed of 1s).

$$\begin{aligned} x &= Z\,\mathbf{1} + f \\ x' &= \mathbf{1}'\,Z + v' + m' \end{aligned} \quad (3)$$

The first equation is a representation where Z **1** corresponds to a column vector consisting of the totals of the row elements of Z, focusing on the use of outputs. Meanwhile, the second equation is a representation in which $\mathbf{1}'Z$ is a row vector consisting of the totals of the column elements of Z, focusing on the production of outputs.

From the above basic structure, we derive input coefficients and backward multipliers. The backward multiplier is a concept that enables us to determine how much IT capital is embodied in the gross output of industry j (consumption, investment, exports).

Let us begin by defining the matrix of input coefficients or the input matrix in the following manner:

$$A \equiv Z(D(x))^{-1} \;\; or \;\; Z \equiv A(D(x)) \,. \quad (4)$$

The typical element of this input matrix can be expressed as $a_{ij} \equiv \frac{x_{ij}}{x_j}$, which corresponds to the value of input by industry i required for industry j to produce 1 won worth of output. Here $D(x)$ is a diagonal matrix with diagonal elements filled with the elements of x.

Using this input matrix, we define the direct backward linkage of industry j in the following fashion:

$$DBL_j \equiv \sum_i a_{ij} \;, \quad (5)$$

where DBL_j is the entire additional input required in industry j to drive up the output by one unit, which is the measure of the direct reliance of industry j on intermediate input.

Now, the Leontief inverse and the total size of the backward linkage of industry j can be obtained through the following steps. The expression $L \equiv (I - A)^{-1}$ is termed a "Leontief inverse" or "output multiplier" and is derived by converting $x = Ax + f$ to $x = Lf$ in the following manner.

$$\begin{aligned} x &= Z\,\mathbf{1} + f \\ &= AD(x)\,\mathbf{1} + f \\ &= Ax + f \\ &\Rightarrow \\ x &= (I - A)^{-1} f \\ &= Lf \end{aligned} \quad (6)$$

The typical element of L, l_{ij}, corresponds to the output by industry i that is directly and indirectly required for industry j to meet 1 won worth of the final demand. The total size of the backward linkage effect (covering both direct and indirect backward linkage effects) to industry j is obtained by $\sum_i l_{ij}$.

The backward multiplier of IT capital is defined similarly. If r is an IT or R&D capital vector, the intensity of IT capital is $\rho_i \equiv \frac{r_i}{x_i}$. This can be re-written as

$$\rho' \equiv r'(D(x))^{-1} \,. \quad (7)$$

In other words, for industry j to meet 1 won worth of the final demand, industry i must produce an output of size l_{ij}, which embodies $\rho_i l_{ij}$ worth of IT capital stock or R&D capital stock. If we are to compute the equivalent amount as applied to all industries, the total sum of the embodied IT or R&D investment required to meet 1 won worth of final demand in industry j is $\beta_i \equiv \sum_i \rho_i l_{ij}$, which is the IT or R&D capital stock backward multiplier of industry j. This can again be expressed as

$$\beta' \equiv \rho' L = r'(D(x))^{-1}(I - A)^{-1} \,. \quad (8)$$

In other words, the backward multiplier of industry j is the sum of all IT capital stocks or R&D capital stocks directly and indirectly embodied to meet 1 won worth of final demand.[1)]

The forward multiplier determines how much of the increase in IT or R&D capital stock in industry i is embodied in outputs by each of the other industries. Let us begin by defining the output coefficient matrix or the output matrix as

$$B \equiv (D(x))^{-1} Z \quad or \quad D(x)B \equiv Z . \tag{9}$$

Expression $b_{ij} \equiv \frac{x_{ij}}{x_i}$, the typical element of the above matrix, corresponds to the amount of the total output by industry i that is sold to industry j. Expression $G \equiv (I - B)^{-1}$, the Ghosh's inverse of the aforementioned output matrix is defined as follows[2)]:

$$\begin{aligned} x' &= 1'\,Z + v' \\ &= 1'\,D(x)B + v' \\ &= x'B + v' \\ &\Rightarrow \\ x' &= v'(I - B)^{-1} \\ &\equiv v'G. \end{aligned} \tag{10}$$

By denoting the typical element of this Ghosh inverse as g_{ij}, we use it to gauge the direct and indirect production costs additionally incurred by industry j, when primary costs rise by 1 won in industry i. The Ghosh inverse is a matrix widely adopted to measure forward linkage effects.

Now, let us define the intensities of different types of final demand as follows: $\varepsilon_i \equiv \frac{e_i}{x_i}$, the typical element of export intensity, indicates the portion of the total output of industry i that is accounted for by exports; $\gamma_i \equiv \frac{c_i}{x_i}$, the typical element of consumption intensity, is a measure of the segment of the output of industry i used up by domestic consumption (consumers and the government); and $\iota_i \equiv \frac{i_i}{x_i}$, the typical element of investment intensity, is equal to the portion of the output of industry i used up by investment. These relations can be expressed as

$$\begin{aligned} \varepsilon &\equiv (D(x))^{-1} e, \\ \gamma &\equiv (D(x))^{-1} c, \\ \iota &\equiv (D(x))^{-1} i. \end{aligned} \tag{11}$$

1) A few words on the calculation of direct and indirect effect are in order here. It is clear that all off-diagonal elements ρ' reflect the indirect effects. The problem is the diagonal elements also include indirect effects. The indirect effects, so called "interindustry feedback effects", should be singled out. For more details, see Dietzenbacher and Los (2002, p. 412).

2) Ghosh [21] originally proposed the forward multiplier as an estimation method for supply quantities rather than to measure cost fluctuation. In this study, we apply the Ghosh inverse as reinterpreted by Dietzenbacher, [22].

Finally, the IT and R&D capital stock forward multiplier is defined in the following manner: since IT and R&D capital stock is a source of the cost shift driving up goods prices, the output value of industry j increases by g_{ij} when IT or R&D capital stock expands by 1 won in industry i. This also entails that the export value of industry j will rise by $g_{ij}\varepsilon_j$, $g_{ij}\varepsilon_j$ being the measure of how much each 1 won increase in the IT or R&D capital stock of industry i is embodied in industry j's exports. Accordingly, the quantitative extent to which an increase in IT capital in industry i by one unit is embodied in a particular industry or in the overall industry is represented by the following expressions, each corresponding to one of the three types of final demand.

$$\begin{aligned} \varphi_i^{\exp} &\equiv g_{ij}\varepsilon_j \quad or \quad \varphi^{\exp} \equiv G\varepsilon = (I - B)^{-1}(D(x))^{-1} e, \\ \varphi_i^{con} &\equiv g_{ij}\gamma_j \quad or \quad \varphi^{con} \equiv G_\gamma = (I - B)^{-1}(D(x))^{-1} c, \\ \varphi_i^{inv} &\equiv g_{ij}\iota_j \quad or \quad \varphi^{inv} \equiv G_\iota = (I - B)^{-1}(D(x))^{-1} i. \end{aligned} \tag{12}$$

We measure the IT and R&D stock backward and forward multipliers in relation to the final demand as a whole. However, using the same method, we also obtain separate estimates of the linkage effects of IT and R&D capital stocks in relation to each of the components of final demand (consumption, capital construction and investment).

2. Forecasting Direct and External Economic Effects

It is also important to conduct a prediction of the future trends based on the historical measurements of the economic effects. This section briefly describes how to form a prediction of the economic effects based on the transition multiplier matrix, which will produce the direct and external economic effects of IT capitals for the future. First, the transition probability is calculated by the Stochastic Kernel Estimation method, using the multiplier matrices of the past 20 years (matching the years 1985 to 1995 and 1990 to 2000, obtained by the methodology as described in the previous subsection). Then, the multiplier matrix for the future is estimated (refer to Bianchi [23] and Quah [24]). Let us denote the matrix of the current IT/R&D forward/backward multipliers by H_t, and that of the multipliers for a future year (s years from now) by H_{t+s}. In the empirical section, we are interested in the prediction of H_{t+10}.

We now describe the steps in detail. First, the calculated direct and indirect multiplier matrix H_t forms a single distribution F_t, and the probability measurement of this distribution is expressed as ϕ_t. ϕ_t takes an evolutionary sequential process and we need to find the law of motion. For this purpose, we assume that ϕ_t evolves according to a

Table 1. IT and R&D capital stocks in nine industries (unit: 100 million won, constant 1995 price).

Industry	1985		1990		1995		2000	
	IT	R&D	IT	R&D	IT	R&D	IT	R&D
Agriculture, fisheries & forestry	74	201	178	326	325	550	829	689
Mining	119	164	129	220	112	277	248	558
Manufacturing	11,949	36,332	36,044	92,148	109,010	170,254	424,979	249,821
Electricity, gas & water	418	389	783	1,129	1,800	4,182	5,931	6,138
Construction	12,359	1,050	24,670	3,671	37,714	12,885	45,215	13,596
Wholesale & retail, restaurant & hospitality	37	314	78	352	236	1,366	969	4,219
Transportation, telecommunications & warehousing	1,688	453	4,794	2,417	15,793	6,298	47,061	15,340
Financial, insurance, real estate & business service industry	285	726	1,294	1,733	3,183	5,956	15,060	11,934
Other service industry	4,958	3,236	8,782	9,833	18,162	31,509	55,536	52,473

Note: The total amounts of R&D capital may partially overlap the IT capital.

primary first order autoregressive process, whose dynamic process $\{\phi_t : t \geq 0\}$ is summarized as

$$\phi_t = \lambda^*(\phi_{t-1}, \varepsilon_t) = \lambda^*_{\varepsilon_t}(\phi_{t-1}), \quad t \geq 1, \tag{14}$$

where λ^* is the operator that maps the measured value with error to the probability measurement.

Next, each coefficient of the given measurement multiplier may transmit to other sectors located at other rows and columns since two categories of economic effects were measured for nine aggregate industries with regard to the IT and R&D capitals. Assuming that P_t is the transition probability matrix, the transition probability can be calculated using the Stochastic Kernel method. That is, the law of motion for ϕ_{t+s} can be computed as

$$\phi_{t+s} = (P_t^s)' \phi_t, \quad \forall s \geq 1. \tag{15}$$

If $s \to \infty$, the ergodic law of motion of ϕ_t can be measured. In this study, only the future H_{t+10} is analyzed.3) We can predict the matrix of the forward and backward multipliers that show the economic effects of two capitals for the next 10 years to come. Based on these predicted values, we can draw objective policy suggestions for the future in formulating IT and R&D policies.

3) The Kernel Density estimation value is used in this study to estimate the multiplier distribution, which shows the future economic effect, whereas the bandwidth is selected according to the bandwidth selection method proposed by Silverman [25].

III. Empirical Results

1. Data and Industry Re-classification

In this study, we use the expanded data set consisting of Korean input-output tables for the years 1985, 1990, 1995 and 2000, IT capital stock data for the nine aggregate industries compiled by Cho and Jeong [18], and R&D capital stock data

Table 2. Industry re-classification.

Classification no. assigned by the study	Industry	Input-output table code (as of 2000)
1	Agriculture, fisheries & forestry	1－30
2	Mining	31－45
3	Manufacturing	46－304
4	Electricity, gas & water	305－311
5	Construction	312－328
6	Wholesale & retail, restaurant & hospitality	329－332
7	Transportation, telecommunication & warehousing	333－351
8	Finance, insurance, real estate & service industries	352－360
9	Other service industries	352－404

Note: The above industry codes from the input-output table are current as of the year 2000. Industry codes for the other years (1985, 1990 and 1995) are adjusted as appropriate.

Table 3. Backward externalities of IT capital stock.

Industry	Total backward multiplier				Indirect backward multiplier (externality)			
	1985	1990	1995	2000	1985	1990	1995	2000
Agriculture, fisheries & forestry (1)	0.0121	0.0103	0.0114	0.0216	0.0118	0.0096	0.0103	0.0193
Mining (2)	0.0123	0.0113	0.0179	0.0519	0.0058	0.0065	0.0144	0.0426
Manufacturing (3)	0.0707	0.0998	0.2060	0.4120	0.0534	0.0703	0.1539	0.2805
Electricity, gas & water (4)	0.0249	0.0268	0.0520	0.0929	0.0145	0.0157	0.0382	0.0716
Construction (5)	0.0618	0.0712	0.1287	0.2022	0.0209	0.0314	0.0829	0.1567
Wholesale & retail, restaurant & hospitality (6)	0.0061	0.0085	0.0142	0.0741	0.0060	0.0082	0.0138	0.0732
Transportation, telecommunications, warehousing (7)	0.0220	0.0365	0.0775	0.1561	0.0121	0.0185	0.0382	0.0880
Financial, insurance, real estate, business service industries (8)	0.0104	0.0170	0.0290	0.0394	0.0093	0.0144	0.0254	0.0275
Other service industry (9)	0.0245	0.0314	0.0574	0.0981	0.0097	0.0156	0.0344	0.0689
Industry average	0.0272	0.0347	0.0660	0.1276	0.0159	0.0211	0.0454	0.0920

for the nine aggregate industries compiled by Seo and Jeong [19]. We refer to Cho and Jeong [18] and Seo and Jeong [19] for detailed explanations on the estimation of IT capital stock and R&D capital stock. Table 1 presents the numerical values of the IT capital stock and R&D capital stock used in this study. As can be seen in Table 1, the amount of IT and R&D capital stocks in Korea has been on a continuously rising trend ever since 1985. In particular, the IT capital stock is increasing faster than the R&D capital stock.

The classification of the nine aggregate industries is tabulated in Table 2. The original Korean Input-Output Tables by the Bank of Korea [20] include 404 basic industries, which are aggregated into nine aggregate industries. The Bank of Korea [20] officially published the inter-industry input-output table for the year 2000 in June 2004.

2. Empirical Results on IT Capital Stock

We present the empirical results of the backward multipliers and forward multipliers of IT capital. Table 3 compares the backward multipliers in nine aggregate industries, which measure the extent to which an increase in final demand by one unit causes an increase in IT capital stocks.

We make the following observations from Table 3. First, during the period from 1985 to 2000, both the total backward multiplier effect and the indirect multiplier effect, excluding the portion of the multiplier effect of any industry belonging to itself, increased in all 9 industries. Second, the manufacturing industry exhibited the strongest backward multipliers, both in the sum of total effect and in its indirect effect (externality). The construction industry follows the manufacturing industry. In these industries, IT capital accumulation has been caused by an increase in final demand from 1998 to 2000. Particularly, IT capital accumulation in the manufacturing industry is the most sensitive to an increase in final demand.

Table 4 presents forward multipliers, which correspond to quantified measures of cost shift onto customer industries resulting from the investment in IT capital stocks in each industry. The results in Table 4 can be summarized as follows: First, just like the backward multiplier effect of IT capital, its forward multiplier effect steadily increased during the 15-year period leading up to the year 2000. And it surged distinctively from 1995 onwards. Second, the forward multiplier effect was the second strongest in the manufacturing industry in 1985, and thereafter the strongest in the manufacturing industry. The forward multiplier in the manufacturing industry experienced an especially sharp rise in the year 2000. The indirect forward multiplier, corresponding to the multiplier effect only affecting industries other than the industry generating the effect, was the strongest in the construction industry until the year 1995. However, the manufacturing industry was the strongest in 2000. The empirical results on the forward multiplier effect imply that in Korea, IT capital accumulation increasingly affected other industries and became a cost factor for the very industry with the increase in IT capital accumulation as well as in other industries.

Next, we turn to an inter-industry comparison of the relative sizes of indirect multipliers to the total multipliers by examining Tables 5 and 6. Table 5 tabulates the ratios of the backward multipliers applying to other industries to a given industry's total backward multipliers. The wholesale & retail, restaurant & hospitality industry appeared to make the

Table 4. Forward externalities of IT capital stock.

Industry	Total forward multiplier				Indirect forward multiplier (externality)			
	1985	1990	1995	2000	1985	1990	1995	2000
Agriculture, fisheries & forestry (1)	0.0043	0.0070	0.0082	0.0200	0.0033	0.0043	0.0051	0.0158
Mining (2)	0.0526	0.0346	0.0272	0.1549	0.0328	0.0193	0.0209	0.1305
Manufacturing (3)	0.7324	1.1212	2.7286	9.9566	0.3338	0.5247	1.5349	6.0442
Electricity, gas & water (4)	0.1565	0.1138	0.2230	0.4901	0.1511	0.1094	0.2204	0.4865
Construction (5)	0.9388	0.9205	1.8393	2.6279	0.8983	0.9915	1.8360	2.6177
Wholesale & retail, restaurant & hospitality (6)	0.0034	0.0039	0.0067	0.0331	0.0009	0.0011	0.0027	0.0234
Transportation, telecommunications & warehousing (7)	0.3259	0.5719	1.5440	3.5769	0.1124	0.2205	0.6407	1.7692
Financial, insurance, real estate & business service industry (8)	0.0087	0.0224	0.0372	0.1057	0.0070	0.0193	0.0321	0.0900
Other service industry (9)	0.1526	0.1808	0.3890	0.7640	0.1420	0.1729	0.3716	0.6937
Industry average	0.2639	0.3307	0.7559	1.9699	0.1869	0.2203	0.5183	1.3190

Note: All forward multipliers in the above table have been multiplied by 100.

Table 5. Inter-industry comparison of IT capital stock for backward externalities and changes over time.

Industry	Indirect backward multiplier to total backward multiplier ratio			
	1985	1990	1995	2000
Agriculture, fisheries & forestry (1)	0.9757	0.9356	0.9056	0.8946
Mining (2)	0.4753	0.5736	0.8058	0.8195
Manufacturing (3)	0.7554	0.7038	0.7468	0.6810
Electricity, gas & water (4)	0.5797	0.5859	0.7344	0.7713
Construction (5)	0.3378	0.4408	0.6446	0.7747
Wholesale & retail, restaurant & hospitality (6)	0.9709	0.9748	0.9704	0.9877
Transportation, telecommunications & warehousing (7)	0.5492	0.5052	0.4937	0.5637
Financial, insurance, real estate & business service industry (8)	0.8922	0.8465	0.8765	0.6980
Other service industry (9)	0.3960	0.4958	0.5984	0.7018
Industry average	0.6591	0.6736	0.7529	0.7658

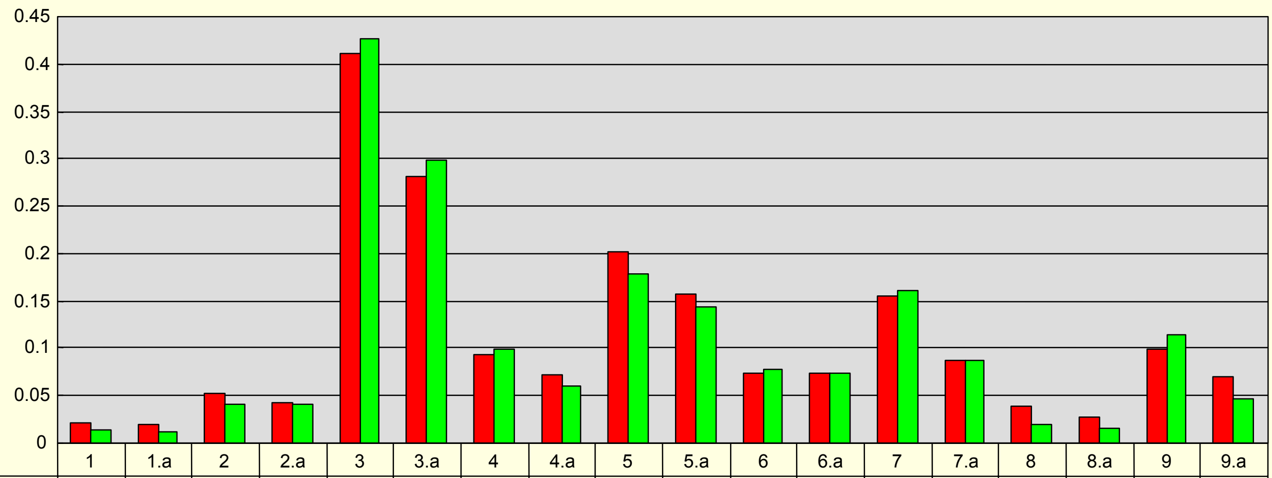
strongest impact on other industries by accumulation of IT capital stock. IT capital accumulation in the wholesale & retail, restaurant & hospitality industry is the most sensitive to other industries, whereas an increase in final demand in the transportation, telecommunications & warehousing industry produces the most robust intra-industry effect, augmenting IT capital stock within itself without encouraging IT capital accumulation in other industries.

Table 6 tabulates the ratios of forward multipliers generating spillover effects to other industries to the total forward multipliers. Industries exhibiting the highest forward spillover effects were the electricity, gas & water industry and the construction industry. The manufacturing and transportation, telecommunications & warehousing industries appeared to generate the lowest forward spillover, which implies that the electricity, gas and water industry has a structure where its cost is transferred to its sub-industries more than other industries.

Last, the multiplier matrix is formed to conduct a forecasting exercise using the coefficients measuring the external economic effects, which are the direct and indirect effects described above. For simplicity, only the backward multiplier

Table 6. Inter-industry comparison of IT capital stock for forward externalities and changes over time.

Industry	Indirect forward multiplier to total forward multiplier ratio			
	1985	1990	1995	2000
Agriculture, fisheries & forestry (1)	0.7505	0.6060	0.6152	0.7907
Mining (2)	0.6239	0.5558	0.7678	0.8426
Manufacturing (3)	0.4558	0.4680	0.5625	0.6071
Electricity, gas & water (4)	0.9656	0.9616	0.9880	0.9927
Construction (5)	0.9568	0.9902	0.9982	0.9961
Wholesale & retail, restaurant & hospitality (6)	0.2811	0.2920	0.4059	0.7046
Transportation, telecommunications & warehousing (7)	0.3450	0.3856	0.4150	0.4946
Financial, insurance, real estate & business service industry (8)	0.8065	0.8604	0.8617	0.8520
Other service industry (9)	0.9300	0.9560	0.9552	0.9079
Industry average	0.6795	0.6751	0.7299	0.7987



	1	1.a	2	2.a	3	3.a	4	4.a	5	5.a	6	6.a	7	7.a	8	8.a	9	9.a
2000	0.022	0.019	0.052	0.043	0.412	0.281	0.093	0.072	0.202	0.157	0.074	0.073	0.156	0.088	0.039	0.028	0.098	0.069
2010	0.013	0.012	0.04	0.04	0.426	0.299	0.1	0.059	0.179	0.143	0.077	0.074	0.16	0.088	0.019	0.015	0.114	0.046

Note: Numbers in the x-axis denote the industry codes, where extension ".a" denotes the external (i.e. indirect) economic effects of the corresponding industries.

Fig. 1. Comparison of IT capital's direct and indirect economic effect in 2010.

effects were examined, as shown in Fig. 1[4)].

The results of the forecasting exercise incorporated in Fig. 1 indicate that even though the backward effects of IT capital seem to have remained at similar levels over the past 20 years, the manufacturing industry will continue to exert a significant backward effect in 2010, and that the "other service industry" seems to exert a larger effect. The results mean that manufacturing sectors will be in a dominant role in producing an external effect on other sectors in next decade.

To sum up, we have observed three notable characteristics from the above results. First, the industry whose increase in final demand augments IT capital stocks most heavily was the manufacturing industry. Second, the industries generating the strongest impact to drive up product prices in customer industries were the construction industry during the 1980s and manufacturing industry during the 1990s. Finally, the industries with the highest inter-industry linkage effect affecting other industries—excluding intra-industry effects—were the wholesale & retail, restaurant & hospitality industry in

4) The reason why we show only the backward economic effect of the IT and R&D capital in 2010 is that the extent of the forward effect is relative and shows the same pattern with the backward effect. Therefore, it is not explained in this study on account of space considerations.

Table 7. Backward externalities of R&D capital stock.

Industry	Total backward multiplier				Indirect backward multiplier (externality)			
	1985	1990	1995	2000	1985	1990	1995	2000
Agriculture, fisheries & forestry (1)	0.0158	0.0144	0.0130	0.0128	0.0151	0.0132	0.0112	0.0109
Mining (2)	0.0155	0.0168	0.0261	0.0478	0.0067	0.0085	0.0175	0.0267
Manufacturing (3)	0.0911	0.1379	0.2259	0.2303	0.0385	0.0623	0.1444	0.1531
Electricity, gas & water (4)	0.0280	0.0374	0.0747	0.0665	0.0183	0.0214	0.0427	0.0445
Construction (5)	0.0300	0.0489	0.1068	0.1015	0.0265	0.0430	0.0912	0.0878
Wholesale & retail, restaurant & hospitality (6)	0.0079	0.0114	0.0176	0.0451	0.0064	0.0104	0.0152	0.0412
Transportation, telecommunications, warehousing (7)	0.0177	0.0341	0.0058	0.0720	0.0151	0.0250	0.0424	0.0498
Financial, insurance, real estate, business service industry (8)	0.0109	0.0191	0.0330	0.0249	0.0080	0.0156	0.0026	0.0015
Other service industry (9)	0.0209	0.0378	0.0770	0.0660	0.0113	0.0201	0.0370	0.0383
Industry average	0.0264	0.0397	0.0702	0.0741	0.0162	0.0244	0.0475	0.0520

Table 8. Forward externalities of R&D capital stock.

Industry	Total forward multiplier				Indirect forward multiplier (externality)			
	1985	1990	1995	2000	1985	1990	1995	2000
Agriculture, fisheries & forestry (1)	0.0117	0.0128	0.0138	0.0165	0.0088	0.0078	0.0085	0.0131
Mining (2)	0.0721	0.0591	0.0668	0.3480	0.0450	0.0328	0.0513	0.2932
Manufacturing (3)	2.2269	2.8664	4.2616	5.8528	1.0150	1.3413	2.3972	3.5530
Electricity, gas & water (4)	0.1452	0.1638	0.5179	0.5071	0.1403	0.1575	0.5117	0.5034
Construction (5)	0.0798	0.1369	0.6283	0.7901	0.0763	0.1356	0.6272	0.7871
Wholesale & retail, restaurant & hospitality (6)	0.0283	0.0176	0.0387	0.1441	0.0079	0.0051	0.0157	0.1015
Transportation, telecommunications & warehousing (7)	0.0874	0.2883	0.6156	1.1659	0.0301	0.1111	0.2554	0.5766
Financial, insurance, real estate & business service industry (8)	0.0220	0.0299	0.0696	0.0837	0.0178	0.0257	0.0645	0.0755
Other service industry (9)	0.0996	0.2024	0.6748	0.7218	0.0926	0.1935	0.6446	0.6553
Industry average	0.3081	0.4197	0.7652	1.0700	0.1593	0.2234	0.5079	0.7283

Note: All forward multipliers in the above table have been multiplied by 100.

backward linkage effect and the electricity, gas & water industry in forward linkage effect. Our forecasting exercise indicates that the backward effect of the current IT capital seems to continue for the next 10 years.

3. Empirical Results on R&D Capital Stock

In this section, we present empirical results on the backward multipliers and forward multipliers of R&D capital. Table 7 compares the backward multipliers across nine aggregate industries, where a backward multiplier measures the extent to which an increase in final demand by one unit causes an increase of R&D capital stocks.

The key results reported in Table 7 are the following: First, during the period from 1985 to 2000, both the total backward multiplier effect and the indirect multiplier effect of R&D capital accumulation, the latter of which excludes the portion of the multiplier effect within its own industry, increased across all nine industries. Second, the manufacturing industry has the strongest backward multipliers, both in the total effect and in the indirect effect (externality). On the other hand, the agriculture, construction, financial, real estate and service

Table 9. Inter-industry comparison of R&D capital stock for backward externalities and changes over time.

Industry	Indirect backward multiplier to total backward multiplier ratio			
	1985	1990	1995	2000
Agriculture, fisheries & forestry (1)	0.9501	0.9160	0.8616	0.8522
Mining (2)	0.4324	0.5107	0.6738	0.5596
Manufacturing (3)	0.4229	0.4526	0.6393	0.6646
Electricity, gas & water (4)	0.6529	0.5729	0.5712	0.6696
Construction (5)	0.8842	0.8788	0.8538	0.8651
Wholesale & retail, restaurant & hospitality (6)	0.8104	0.9156	0.8621	0.9125
Transportation, telecommunications & warehousing (7)	0.8505	0.7333	0.7305	0.6918
Financial, insurance, real estate & business service industry (8)	0.7382	0.8173	0.7972	0.6218
Other service industry (9)	0.5400	0.5322	0.4806	0.5811
Industry average	0.6136	0.6140	0.6770	0.7016

Table 10. Inter-industry comparison of IT capital stock for forward externalities and changes over time.

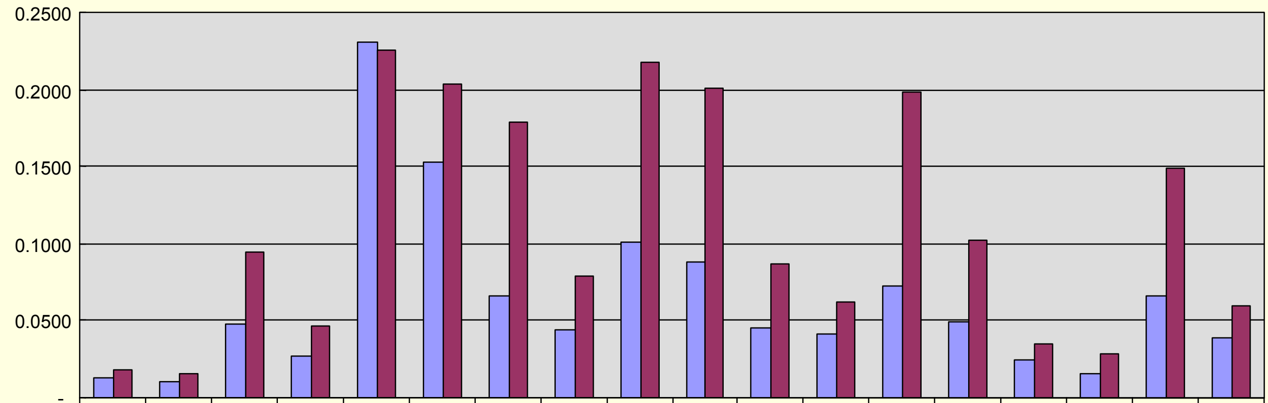
Industry	Indirect forward multiplier to total forward multiplier ratio			
	1985	1990	1995	2000
Agriculture, fisheries & forestry (1)	0.7504	0.6059	0.6152	0.7907
Mining (2)	0.6238	0.5558	0.7678	0.8425
Manufacturing (3)	0.4557	0.4679	0.5625	0.6070
Electricity, gas & water (4)	0.9656	0.9615	0.9879	0.9927
Construction (5)	0.9568	0.9901	0.9981	0.9961
Wholesale & retail, restaurant & hospitality (6)	0.2810	0.2919	0.4059	0.7046
Transportation, telecommunications & warehousing (7)	0.3449	0.3856	0.4149	0.4946
Financial, insurance, real estate & business service industry (8)	0.8065	0.8604	0.8617	0.8519
Other service industry (9)	0.9299	0.9559	0.9551	0.9078
Industry average	0.5170	0.5323	0.6637	0.6806

industries have had declining backward multiplier effects since 1995.

Table 8 tabulates forward multipliers, which quantify cost shifts onto customer industries resulting from investment in R&D capital stocks in each industry. The key results reported in Table 8 are the following: First, just like the backward multiplier effect of IT capital, the forward multiplier effect of R&D capital steadily increased during the 15 year period leading up to the year 2000. And it has surged more distinctively from 1995 and onwards. Second, the manufacturing industry generally has the strongest multiplier effect, while the multiplier effect of the transportation, telecommunications & warehousing industry has increased significantly from 1990. If an increase in the forward multiplier effect drives cost upward in the backward industry with more investment in R&D, it may imply that the Korean industrial structure is continuously deteriorating with increasing investment in R&D.

Next, Tables 9 and 10 compare the multiplier effects of an industry within that industry and on other industries. Table 9 tabulates the ratio of the indirect backward multiplier applying to other industries to the total backward multiplier. The R&D capital stocks in the agriculture industry, and the wholesale & retail, restaurant & hospitality industry affect other industries the most. In contrast, the manufacturing industry shows a relatively low forward spillover effect compared to other industries.

Table 10 tabulates the ratios of the forward multiplier (creating spillover effect) of the R&D capital stock to other industries to the total forward multiplier. Industries exhibiting



	1	1.a	2	2.a	3	3.a	4	4.a	5	5.a	6	6.a	7	7.a	8	8.a	9	9.a
2000	0.012	0.010	0.047	0.026	0.230	0.153	0.066	0.044	0.101	0.087	0.045	0.041	0.072	0.049	0.024	0.015	0.066	0.038
2010	0.018	0.015	0.095	0.046	0.225	0.203	0.178	0.078	0.217	0.201	0.087	0.062	0.198	0.102	0.034	0.028	0.148	0.059

Note: Numbers in the x-axis denote the industry, where extension ".a" denotes the external (i.e. indirect) economic effect of the corresponding industry.

Fig. 2. Comparison of R&D capital's direct and external economic effects in 2010.

the highest forward spillover effect were the electricity, gas & water industry and the construction industry. The wholesale & retail, restaurant & hospitality industry as well as the manufacturing industry had the weakest effect. Another conspicuous characteristic is that the forward multiplier to other industries relative to the forward multiplier within the industry rose sharply after the 1980s and early 1990s.

Finally, Fig. 2 displays the result of a forecasting exercise on the R&D capital's backward effect. The most outstanding characteristics of the forecast for 2010 on the backward effect of the R&D capital are that the manufacturing industry will have the strongest backward effect, and the construction and transportation, telecommunication & warehousing industry will have sharply increased backward effects. The indirect effect (external economic effect) will be conspicuous in all industries. Even though the overall shape of the R&D capital's backward effect and the IT capital's backward effect are the same, their quantitative natures are very different from each other.

We summarize key empirical observations of the R&D capital's externality effect. First, the manufacturing industry experienced the heaviest augmentation of R&D capital stock with an increase in its final demand. Second, the manufacturing industry also gave rise to cost increases of its sub-industries most significantly with accumulation of the R&D capital. These two empirical observations for Korean industries are in agreement to the observations made by other studies on U.S. industry structure (Refer to Dietzenbacher et al [17], p. 421). In terms of externality effect, measuring the portion of economic affect on other industries excluding the portion within the industry, the backward effect of the R&D capital stock was the strongest in the agriculture industry and in the wholesale & retail, restaurant & hospitality industry, whereas the electricity, gas & water industry and the construction industry had the strongest forward effects. Finally, based on a forecasting exercise we observe that the economic backward effect, and especially the external economic effect, will increase in 2010 among all industries.

4. IT Capital Stock and R&D Capital Stock

IT and R&D capital accumulations have affected the national economy continuously through the forward and backward effect, and the effects are getting stronger. However, comparing the economic linkage effect of IT and R&D capital since 1995, the forward and backward linkage effects of IT capital are more conspicuous than that of R&D capital.

Examining externalities of IT and R&D capital, the manufacturing industry has relatively smaller external effects. This may indicate that the manufacturing industry is losing linkage with other industries. Weak linkage of the manufacturing industry to other industries is more pronounced in forward linkage effects than in backward linkage effects. However, our forecasting exercise indicates that the linkage of the manufacturing industry with other industries is forecast to improve significantly by 2010. The improvement in linkage is especially pronounced in R&D capital.

From the viewpoint of an industry policy, since the manufacturing industry contains many high-tech industries, the demand-management oriented industry policy can strengthen international competitiveness by inducing IT and R&D capital accumulation[5].

IV. Conclusion and Implications

We measured externalities of IT and R&D capital stocks using the inter-industry input-output tables. The recent Korean experience with the huge increase of IT investment is resulting from an externality based on inter-industry IT capital accumulation. Our empirical results support the new growth literature and are against the Solow IT paradox, at least in Korea. The analysis also indicates that the existence of a large IT capital externality supports a successful experience of the growth effects of the IT industry in Korea.

Key findings of this study are the following: First, we have observed continuous intensification of IT capital in all nine aggregate industries for the study period from 1985 to 2000. Accumulation of the R&D capital followed a similar trend. Second, the backward multiplier effect of IT capital stock was the strongest in the manufacturing industry. In addition, the indirect backward multiplier effect was also the strongest in the manufacturing industry. Third, the forward multiplier effect of IT capital stock was the most substantial in the construction industry during the 1980s, and thereafter in the manufacturing industry. However, the forward multiplier effect of R&D capital stock was the most substantial in the manufacturing industry throughout the study period. The indirect forward multiplier effect was observed to be the strongest in the construction industry until 1995, and in manufacturing in 2000. IT capital has been more dynamic than R&D capital in terms of the effect on the industry structure. For the economic externality effect, the wholesale & retail, restaurant & hospitality industry exhibits the strongest backward effect, whereas the electricity, gas, water industry and the construction industry exhibits the strongest forward effect. On the other hand, for the economic externality effect, the agriculture industry, and the wholesale & retail, restaurant & hospitality industry had the strongest backward effect, and the electricity, gas & water industry and the construction industry had the strongest forward effect. Last, our forecast based on the multiplier matrices of the two capitals states that the economic backward effect, especially the external economic effect, will increase through 2010 in all industries.

Policy implications drawn from these key findings are the following: First, in order to maximize the forward and backward effects of the ever-increasing IT capital, our industry policy should focus on reducing the cost of capital accumulation in the manufacturing industry, which is understood as the core industry, through productivity improvement and promotion in the IT industry. Second, we need a policy that encourages an increase in final demand to continuously induce IT and R&D capital accumulation. Hence, it is important to make an effort to reduce the cost that is transferred from the electricity, gas & water industry and the construction industry, which had the biggest ratio of cost spillover in IT and R&D capital accumulation, in order to enhance price competitiveness of the domestic products. Additionally, the cost transfer ratio for R&D capital accumulation is found to be larger than that of IT capital.

A limitation of this study is that even though we adopted the methodology that compares and evaluates the economic effect of IT and R&D capital, our analysis did not fully incorporate the dynamic nature of these two capitals. The problem of interpreting the study results based on the input-output table is that a precise measurement of externality in I/O methodology is limited for the production function form with a fixed coefficient. The other weakness of the present study is not considering the source of R&D expenditure. The difference in the sources of R&D expenditure may influence the degree of R&D externality.[6]

5) There are arguments about superiority between the industry policy of the traditional Demand Pull type and that of the Technology Push type from the aspect of industry development and competitiveness enhancement. It appears that the Demand Pull policy is superior in this study. For an extensive discussion of industry policy and protection of R&D see also Rim [26] and Park [27].

6) Authors would like to thank an anonymous referee for the pointing this out.

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