Correlation among Measures of Technological Knowledge

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〈 목 차 〉

Summary: In the knowledge-based economy, technological knowledge (TK) is reckoned key subject of knowledge management. Despite growing recognition, it has long been considered an intractable task to develop precise measures of TK and, as a remedy, a number of R&D-related proxy indicators have been employed. Although voluminous previous research has examined the structure and process of technological innovation by using proxy indicators, the inquiry into the relationship among respective indicators has remained unexplored. In this research, we take three most frequent proxy indicators of TK, R&D human resources, R&D stock, and patents, and investigate the correlation among respective measures. In addition, the dynamic pattern of time lag between technological input and output is also analyzed.

1. Introduction

Recently, with the advent of knowledge-based economy, the term of knowledge

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management (KM) has attracted increasing attention from both private sector and public sector alike. The spectrum of KM is so ample, encompassing both codified and tacit, observable and non-observable, positive and negative, autonomous and systematic intellectual capital created, stored and distributed in a variety forms of organization (Teece, 1998). Amongst others, technological knowledge (TK) is reckoned as key subject of KM since it accounts for the principal source of competitiveness and productivity. However, it has long been considered an intractable, if not impossible, task to gauge the amount of TK, as compared to the relative easiness of measuring traditional economic factors like fixed capital and labor. For instance, the neoclassical conception of technology in the form of a production function has proven to be useful for macroeconomic policy-making but its validity has been limited due to the difficulty of separating purely technological variables from non-technological variables and measuring the amounts of related variables.

The inherent difficulty of measurement may be attributable to the following factors. First, TK encompasses heterogeneous and multi-disciplinary components that are hard to standardize (Clark, 1985). Second, TK embraces embodied/tacit knowledge that is hard to separate or quantify (Polanyi, 1966; Dosi, 1982; Nelson and Winter, 1982). Third, TK is subject to idiosyncratic differences across industrial sectors (Pavitt, 1984) and thus is difficult to generalize.

Consequently, it is quite natural that past research has employed various proxy indicators for TK, assuming that TK or intellectual capital is obtained through R&D activities. Along this line, a number of proxy indicators of TK developed and applied thus far can be classified into three categories: R&D input-related indicators, R&D throughput (stock)-related indicators, and R&D output-related indicators. The rationale is straightforward. The input-related indicators are based on the assumption that the amount of TK is determined by the amount of R&D input devoted to the knowledge-generating stage. The throughput-related indicators postulate that the amount of TK can be measured by the cumulative stock of R&D investment. The output-related indicators are due to the hypothesis that the amount of TK is reflected by the amount of R&D outcome.

Although voluminous previous research has examined the structure and process of technological innovation by using various proxy indicators, there has been no attempt to analyze the relationship among proxy indicators. It might be impossible to select the unique best proxy indicator since respective indicators have their own advantages and disadvantages and therefore the selection criteria are situation-specific. However, it is necessary to analyze the relationship among indicators. The analysis may provide valuable information in employing appropriate indicator of TK. Another research theme of interest is to examine the time-lag between technological input and output. It is not uncommon that there exists a long and irregular time interval between R&D input and output and the interval can be measured, albeit approximately, by observing the correlation among indicators. The findings about the time-lag pattern may convey useful information in understanding the nature of innovation process.

The main purpose of this research is two-fold: first, to investigate the correlation among input, throughput and output indicators of TK, and second, to examine the dynamic pattern of time-lag between R&D input and knowledge output. To this end, we first adopt the following three proxy indicators that have been frequently used to gauge the amount of TK: R&D human resource for input indicator, R&D stock for throughput indicator, and patents for output indicator, respectively. Then, individual and pair-wise correlation coefficients are computed to investigate the relationship among respective measures. Finally, we analyze the changing pattern of correlation with respect to time-lag between input and output.

2. Proxy Measures of Technological Knowledge

2.1 R&D Human Resource

In the input side, the amount of R&D human resource is frequently used as a proxy indicator for the capacity of TK base. The rationale for using R&D human resource is based on the assumption that the more human resources a firm (nation) employs, the more technological capability it maintains. It is also postulated that the amount of R&D investment is proportional to the number of R&D personnel. In fact, the amount of R&D human resource has been recommended as an indispensable input indicator in the international R&D survey standards (OECD, 1981). Furthermore, technological diffusion process and inter-industrial innovation flows can be indirectly measured by the degree of mobility of R&D employment across industrial sectors. To illustrate, Leoncini et. al (1996) adopted R&D personnel of each industry as a proxy measure for the innovation capacity. Park and Kim (1999) also used R&D human resources in measuring the flow of technological knowledge across industries. This indicator, albeit simple and useful, has limitation in that technological innovation draws on ideas from various sources other than formal R&D human resource.

2.2 Patents

In the output side, the amount of patents is the most frequent measure adopted in survey practice and analytical research (OECD, 1994). The rationale is due to the hypothesis that technological advances are best conceived in terms of relevant events or inventions, which in turn are registered as patents. Patents meet explicit criteria of originality, technical feasibility, and commercial worth (Kuznets, 1962). Patents also have advantages in terms of availability of database, scope of coverage, and variety of information. Thus, patents have long been considered evidence of innovative performance and generally preferred to other output indicators. In addition, patents have been used to estimate the technology flows and their impact on productivity (Scherer, 1982; Evenson and Puttnam, 1988). Patents, however, are also subject to limitations since many inventions and technological knowledge are not patented and patents, if registered, may differ from one another with respect to qualitative significance. Moreover, the index of patented inventions is merely a list of blueprints available which gives little information on innovative value and commercial use (Sahal, 1981). Patents should therefore at best be considered a partial measure of TK, applicable only in those industrial sectors where patenting is common practice (Tijssen, 2001).

2.3 R&D Stock

In the throughput side, R&D stock reflects the cumulative amount of technological knowledge which a firm or an industry possesses at a certain point in time. The cumulative stock is obtained through R&D investment, technology import, and other inputs. A number of past studies employed the notion of R&D stock, as one of the inputs of the production function, and gauged the cumulative amount in an attempt to estimate the rate of return to R&D investment (Griliches, 1980; Nadiri, 1980; Bernstein and Nadiri, 1988; Mohnen, 1996, etc.). In addition, R&D stock may indicate the future potential to develop new products or processes (Goto et. al, 1989). Although R&D stock is considered a more comprehensive measure, vis--vis R&D personnel or patents, it is more complex and thus is more difficult to quantify (Papaconstaninou et. al, 1998). It also should be noted that R&D stock depreciates and becomes obsolete over time and thus necessitates such additional parameters as depreciation rate, time lag and R&D deflator.

3. Data and Methodology

3.1 Data

The empirical database for this research covers private firms of 16 industries in Korea with the reference period from 1985 to 1997. <Table 1> presents the set of classified industries which is basically in accordance with Korean Standard

〈Table 1〉 List of Selected 16 Industries

	Industry		Industry		Industry		Industry
1	Mining & quarrying	5	Chemicals & allied products	9	General machinery & equipment	13	Other manufacturing
2	Food & beverages	6	Nonmetallic mineral products	10	Electronic & other electric equipment	14	Electric, gas & water services
3	Textile	7	Primary metal products	11	Precision instruments	15	Construction
4	Wood, paper & printing	8	Fabricated metal products	12	Transportation equipment	16	Wholesale & retail trade

Industrial Classification (KSIC) of 1990 but modified and reclassified to some extent to facilitate data-gathering process across three indicators. The modified classification set covers 16 industries, 12 manufacturing sectors and 3 service sectors.

R&D human resource (RDH) data was collected from the Report on the Survey of R&D in Science and Technology (MOST). Patent data (PAT) was due to the Patent Database (KIPRIS) of Korean Intellectual Property Office (KIPO). R&D stock data (RDS) was extracted from the Survey on Industrial Technological Development Cases in Korea (KITA). After gathering raw data and parameters, R&D stock is estimated by the following formula which is based on the method of Griliches (1980), Nadiri (1980) and Goto, et. al. (1989).

$$RDS_t = \sum_{i=1}^{n} \mu_i E_{t-i} + (1-\delta) RDS_{t-1} \qquad (1)$$

Here, RDS_t is the R&D stock in period t, μ is the lag operator that connects past R&D expenditure, E_{t-1}, to current increase in technological knowledge, and δ is the rate of obsolescence of the R&D stock. The increase in R&D stock in period t reflects not only R&D expenditure of period t but also past R&D expenditures that bear fruit in period t. Therefore, in principle should be a distributed lag. However, because it is difficult to get the information to specify the lag structure, we simply used the average lag in each industry and assumed that R&D expenditure in period t- θ contributes to the increase in R&D stock in period t. Thus the above equation (1) reduces to:

$$RDS_t = E_{t-\theta} + (1-\delta) RDS_{t-1} \qquad (2)$$

Further, we assumed that the growth rate of E is the same as the growth rate of RDS. The initial amount of RDS, RDS_0, was obtained as follows:

$$RDS_0 = \frac{E_{1-\theta}}{g+\delta} \qquad (3)$$

where g is the growth rate of E and is the rate of obsolescence of R&D stock of each industry.

3.2 Methodology

As mentioned before, the main objective of this research is to investigate the relationship among three proxy indicators of technological knowledge, R&D human resources, R&D stock, and patents. Accordingly, the primary method is the statistical correlation analysis. We first construct three correlation matrixes for the reference period of 13 years for each indicator. These matrixes may show the changing pattern over time for each indicator. Second, three pair-wise correlation matrixes for the same period are constructed between measures. These matrixes are expected to indicate the correlation, both static and dynamic, between two different indicators. Third, time-lag, pair-wise correlation matrixes are computed by changing the time interval between year points of interest.

4. Results of Analysis

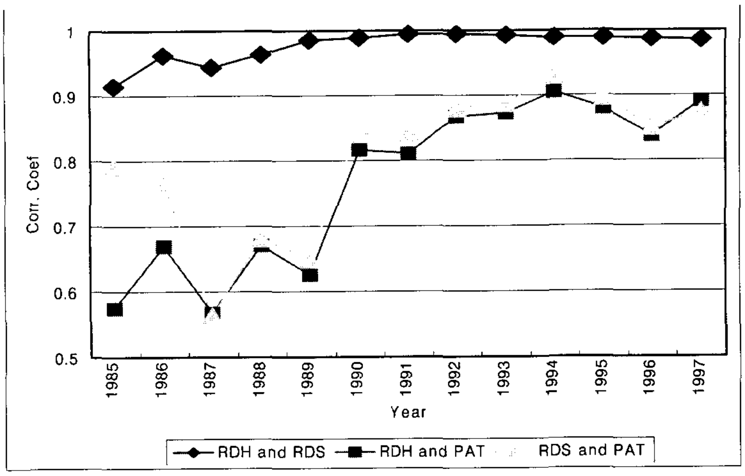
4.1 Correlation Analysis

We first investigated the overall correlation pattern of each proxy indicator. That is, for each measure, the correlation coefficients between two different years are measured. As anticipated, for all indicators, the correlation coefficients over time are high, indicating a strongly positive correlation. However, as summarized <Table 2>, the degree of correlation is higher for RDH (from 0.91 to 0.99) and RDS (0.83 to 0.99) but relatively lower for PAT (0.56 to 0.99). This result implies that annual R&D input amounts and cumulative R&D stock tend to be stable over time but R&D outcomes may vary significantly across years. The finding is not surprising because the rate of R&D output never tends to be constant, even though constant amount of input has been supplied.

The similar tendency is found in pair-wise correlation analysis. As shown in <Figure 1>, the correlation between RDH and RDS appears very high, coefficients from 0.92 to 0.99 (significant at the level of 0.05 and 0.01, respectively), and increases over time. On the contrary, the coefficients of RDH-PAT and RDS-PAT pairs are much lower. Also note that RDH-PAT and RDS-PAT correlation patterns are rather different in the early stage but become strikingly similar over time.

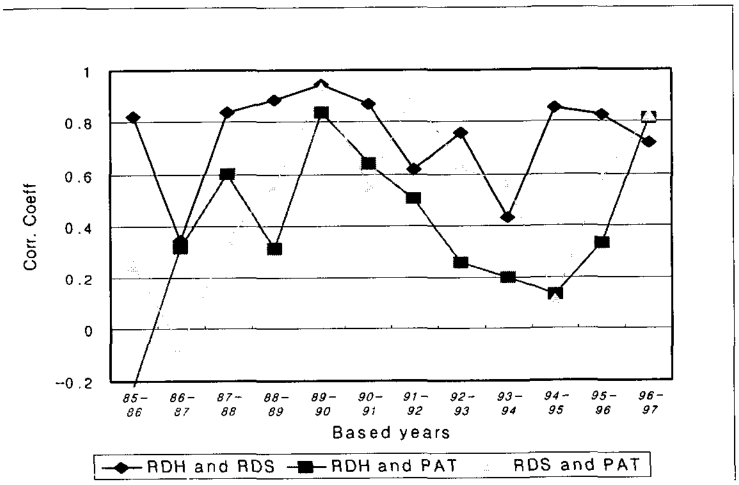
〈Table 2〉 The Results of Correlation Analysis

		1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
RDH	1985	0.997	0.980	0.990	0.993	0.985	0.982	0.982	0.978	0.963	0.962	0.954	0.953
	1986		0.990	0.995	0.988	0.977	0.971	0.970	0.965	0.947	0.947	0.937	0.937
	1987			0.994	0.969	0.953	0.945	0.940	0.934	0.916	0.921	0.908	0.907
	1988				0.987	0.976	0.969	0.964	0.958	0.935	0.943	0.933	0.933
	1989					0.997	0.994	0.991	0.985	0.966	0.971	0.966	0.967
	1990						0.997	0.993	0.985	0.966	0.975	0.972	0.972
	1991							0.998	0.993	0.980	0.987	0.984	0.984
	1992								0.997	0.988	0.990	0.988	0.987
	1993									0.991	0.992	0.990	0.990
	1994										0.995	0.994	0.993
	1995											0.999	0.998
	1996												0.999
		1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
RDS	1985	0.983	0.952	0.934	0.921	0.905	0.883	0.871	0.866	0.866	0.860	0.846	0.830
	1986		0.992	0.983	0.975	0.965	0.952	0.944	0.938	0.935	0.929	0.917	0.903
	1987			0.998	0.994	0.988	0.981	0.975	0.971	0.968	0.963	0.953	0.942
	1988				0.998	0.995	0.991	0.987	0.983	0.979	0.974	0.965	0.955
	1989					0.999	0.996	0.993	0.990	0.988	0.984	0.976	0.967
	1990						0.999	0.997	0.994	0.990	0.986	0.978	0.970
	1991							0.999	0.997	0.993	0.989	0.982	0.974
	1992								0.998	0.995	0.991	0.985	0.978
	1993									0.999	0.997	0.993	0.988
	1994										0.999	0.997	0.993
	1995											0.999	0.996
	1996												0.999
		1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
PAT	1985	0.987	0.990	0.978	0.965	0.867	0.863	0.803	0.765	0.649	0.680	0.732	0.610
	1986		0.982	0.991	0.954	0.889	0.887	0.833	0.795	0.694	0.718	0.763	0.649
	1987			0.975	0.948	0.828	0.828	0.760	0.718	0.597	0.630	0.682	0.558
	1988				0.971	0.910	0.913	0.861	0.827	0.730	0.756	0.796	0.693
	1989					0.933	0.929	0.883	0.858	0.761	0.793	0.837	0.738
	1990						0.996	0.990	0.979	0.937	0.947	0.968	0.914
	1991							0.991	0.978	0.937	0.948	0.965	0.918
	1992								0.996	0.973	0.979	0.989	0.957
	1993									0.984	0.992	0.997	0.974
	1994										0.996	0.988	0.991
	1995											0.996	0.994
	1996												0.983



〈Figure 1〉 Patterns of Pair-wise Coefficients

Since RDH and RDS exhibit a similar pattern, another inquiry of interest is which one is more closely related to PAT. This task can be done by investigating the correlation coefficient of the first differences1) for pair-wise indicators. As portrayed in <Figure 2>, it is rather clear that RDS-PAT pair is more strongly correlated than RDH-PAT pair. The finding indicates that the patenting trend is more accurately described by the cumulative R&D stock than by yearly R&D input.



〈Figure 2〉 First-Difference Pair-wise Coefficients

1) First differences mean simply the changes in the series on each proxy (Johnston, J. and Dinardo, J., 1997).

To recap, the above findings suggest the followings. First, RDH and RDS share similar characteristics in common and thus may be used alternatively as proxy indicators. Second, PAT should be regarded as dissimilar indicator from RDH and RDS and thus be used for different purpose. Third, as compared to RDH, RDS is more closely related to PAT since it represents the throughput side which is somewhere between input (RDH) and output (PAT) in location and exerts a collective effect on output capacity.

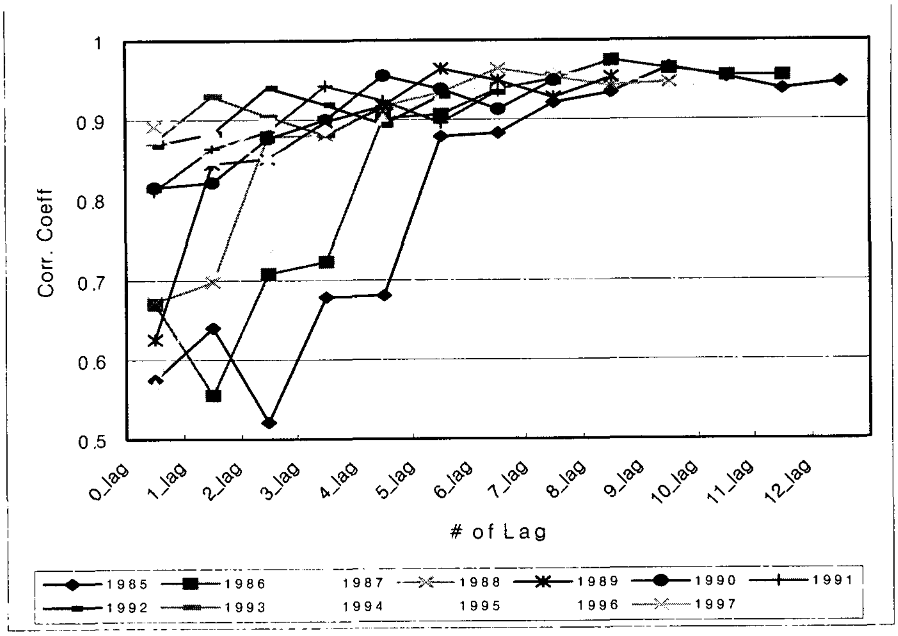
4.2 Time-lag Analysis

The time lag[2] relationship between R&D input and output measures was considered in our analysis. For instance, 5_lag means that the correlation coefficient is calculated between two year-points with the interval of 5 years. The time-lag analysis is conducted based on the hypotheses that (1) there should be some time interval between R&D input (RDH or RDS) and output (PAT) and (2) the correlation between input indicators and output indicators becomes higher as the time lag becomes longer.

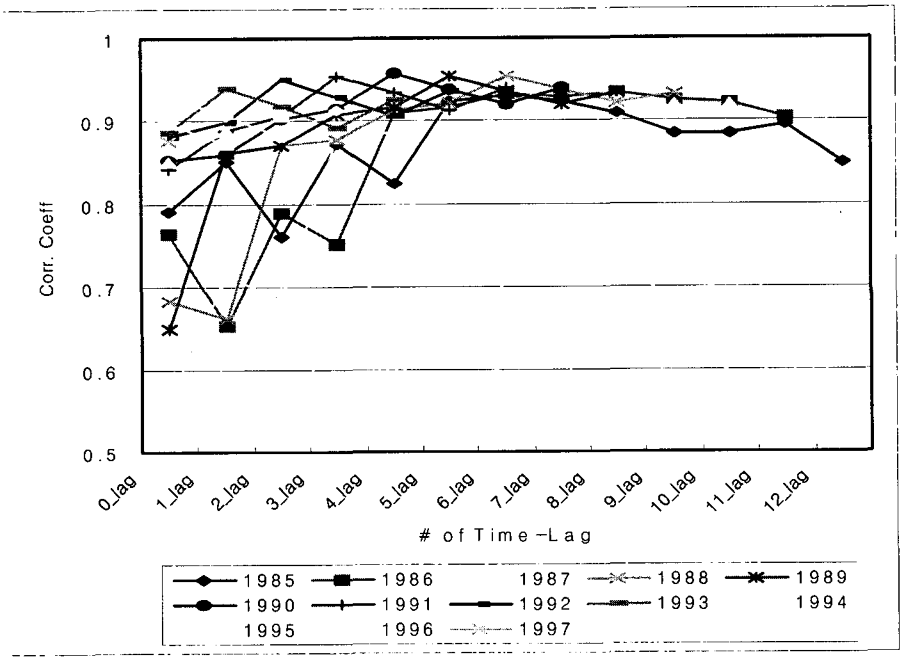
Overall, the results coincide with expectation. As shown in <Figure 3 and 4>, for both RDH-PAT and RDS-PAT, correlation coefficients between input/stock indicator and output indicator tend to become higher as time intervals become longer. However, interestingly, it should be noted that the gaps become narrower in the long run as intervals become longer. For instance, taking the year of 1985 as starting point, 1_lag coefficient (correlation between 1985 and 1986) is below 0.6 but the value increases gradually to reach the peak value of around 0.95 for 8_lag (correlation between 1985 and 1993) and stays at the same level throughout for 9_lag to 12_lag. This finding implies that the time-lag pattern exhibits a converging trend. In summary, the observations fully support the first hypothesis that knowledge input turns into knowledge output after a considerable length of time interval. However, the second hypothesis is partially supported in that the correlation between input indicator and output indicator becomes higher not

2) Time lag is defined as the interval between year-points when the correlation coefficients are measured.

unlimitedly but only until a certain length of time interval.



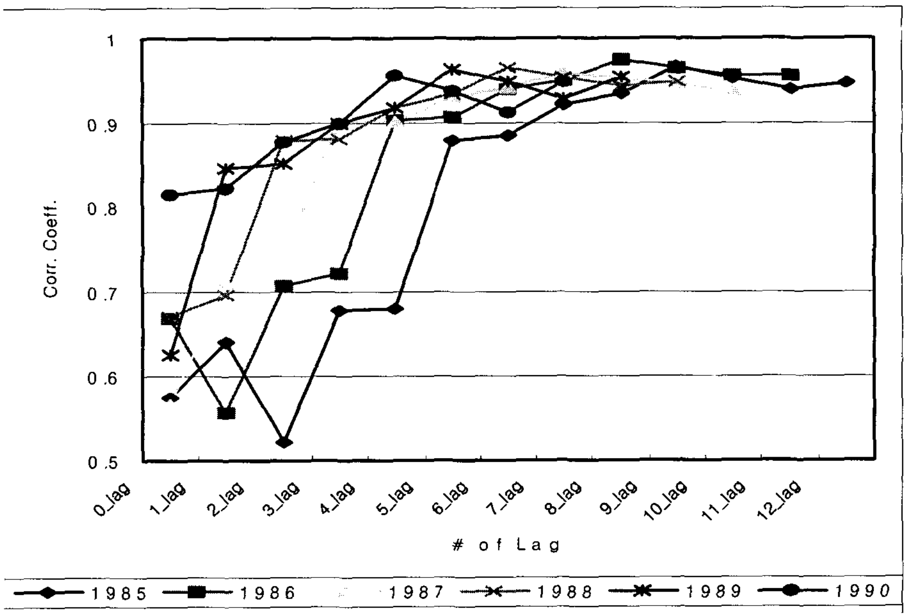
〈Figure 3〉 Time-lag Coefficients of RDH-PAT



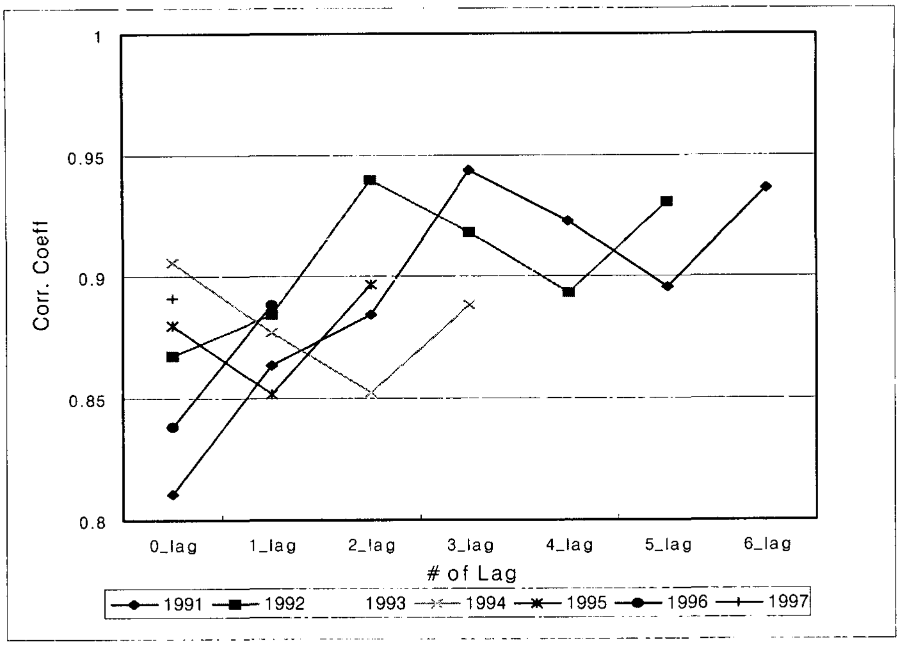
〈Figure 4〉 Time-lag Coefficients of RDS-PAT

The aforementioned findings, although assure the existence of time lag, provide little information on the definite length of time-lag. In other words, it is hard to estimate the length of time interval until knowledge input is converted into knowledge output. Probably, the simplest way to estimate the length of time interval is to measure the time interval between knowledge input (date of R&D launching) and knowledge output (date of patenting) for each R&D project and compute the average length. In an aggregate sense, however, we believe that the average length can be inferred based on the time lag between input indicator and output indicator. That is, the time lag represents the length of time that takes until the correlation between input indicator and output indicator reaches the peak value. A related hypothesis is that the time lag becomes shorter over time.

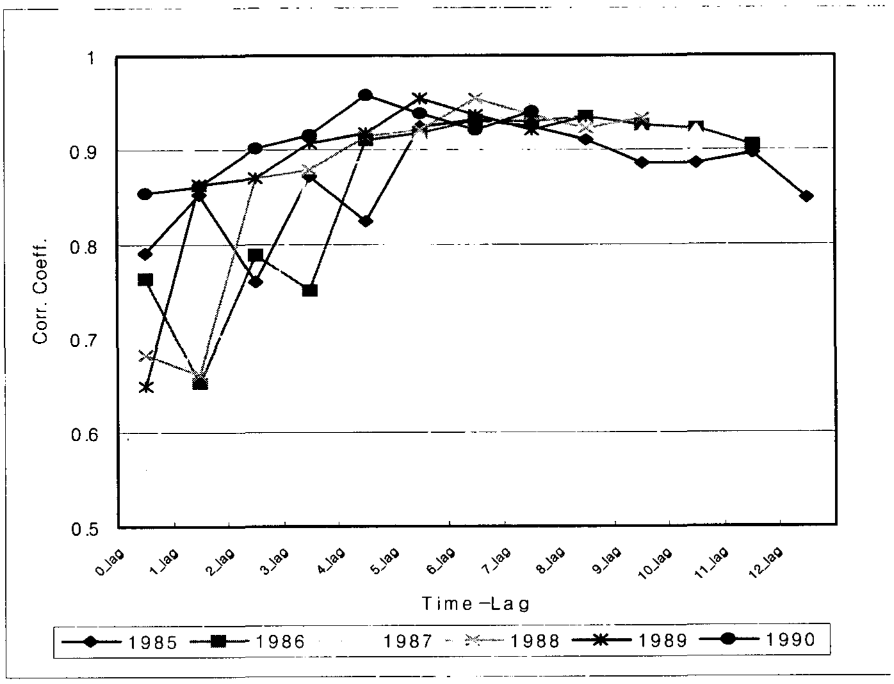
To this end, we divide the whole reference period into two; 1985 to 1990 and 1991 to 1997. As shown in <Figure 5 and 6>, rather intuitively, the average time-lag between RDH and PAT turns out to be 7 years in 1980's but becomes 3-4 years in 1990's. Similarly, as depicted in <Figure 7 and 8>, the average time-lag between RDS and PAT is around 5 years in 1980's but becomes around 2-3 years in 1990s.



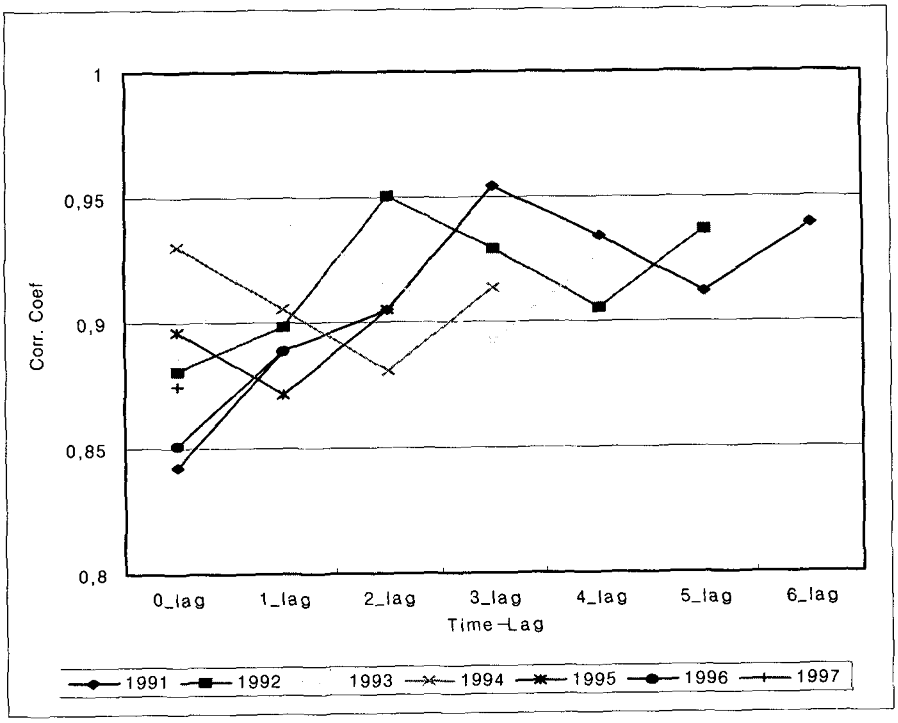
〈Figure 5〉 Coefficients of RDH-PAT in '80s



〈Figure 6〉 Coefficients of RDH-PAT in '90s



〈Figure 7〉 Coefficients of RDS-PAT in '80s



〈Figure 8〉 Coefficients of RDS-PAT in '90s

In general, we may be able to draw the following two conclusions from the above findings. First, it is clear that there exists a time lag between technological input and output. The gap tends to be longer for input (RDH)-output (PAT) but relatively shorter for stock (RDS)-output (PAT). The explanation for this trend was already provided above. Second, the time lag becomes shorter over time. The reason for this trend is two-fold. First, firms have accelerated R&D cycle, time horizon from input to output, to quickly respond to market demands. Second, the overall productivity and innovative capability of firms have increased over time.

5. Concluding Remarks

With the emergence of knowledge-based economy, development of technological knowledge indicators is called for. The selection of appropriate indicator and precise measurement of amount is the preliminary but indispensable step in policy making of public sector and knowledge management of private sector. Focusing on three R&D-related knowledge indicators, namely R&D human resources, R&D stock, and patents, this research examined the relationship among indicators. The pattern of time lag between R&D input and output was also investigated.

The major findings of analysis may be summarized as follow. First, it was identified that input indicator (RDH) and stock indicator (RDS) are quite similar and thus may be used alternatively whereas output indicator (PAT) is considerably different from the former two. Second, it was noted that stock indicator is more closely related to output indicator, vis--vis input indicator. Third, it was found that there exists a considerable length of time lag between technological input and output. Fourth, the length of lag becomes shorter over time.

In nature, this paper represents an exploratory effort toward the complete understanding about characteristics of knowledge indicators. Thus, the current research is subject to some limitations that, at the same time, suggest future research issues. First, the set of indicators employed here is by no means exhaustive. An extension of current study is required by including other proxy indicators than the three measures discussed in this study. Second, this research is based on a pooled database of Korean industries and therefore the results apply only to the reference period of Korea. It is necessary to carry out an industry-specific and/or country-specific analysis for deeper understanding and richer information, by expanding the pool of empirical data. Third, it is imperative to develop flow-related indicators. The knowledge-based economy is characterized by the inter-industrial flow of knowledge and technology fusion. Despite the importance, however, the effort to develop flow-related indicators has been immaterial.

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