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The Economic Growth Effect of R&D Activity in Korea*

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One of the most efficient methods to raise competitiveness in an economy for stable and continuous economic growth comes from research and development (R&D) activities. This paper investigates the contribution effect of R&D stock for economic growth using the R&D based Cobb-Douglas production function during the years 1976-2009. In addition to the past literatures, this paper estimates the contribution of two sourced R&D stocks for economic growth. Based on the empirical results, the traditional production factors — labor and capital — contribute about 65% to economic growth. Also, the contribution ratio of overall R&D stock to economic growth is about 35%. In detail, public and private R&D stocks account for economic growth of about 16% and 19%, respectively.

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1. INTRODUCTION

Economic circumstances in the world have changed rapidly with respect to international competition. Especially, as the change accelerates, it becomes more and more important for an economy to maintain and improve its core competence in order to ensure stable and continuous economic growth. One of the most efficient methods to raise competitiveness in the corresponding economy comes from research and development (R&D) activities. R&D takes a dual role of absorbing existing knowledge created from outside as well as creating new knowledge directly; that is, R&D activities are well known to provide two functions: creation and learning. When specific knowledge that has been created or developed by some agent can be utilized by other agents besides the developer, the knowledge transmission is known as a "spillover effect". Accumulated knowledge causes an innovation to various economic agents, In particular, it enables producers to make new product, to reduce costs in existing production process, and to improve the quality of products.

Therefore, R&D is closely linked to productivity. The existing literature (Griliches, 1980a and 1980b; Griliches & Lichtenberg, 1984; Mansfield, 1988, Wolf & Nadiri, 1993; Hanel, 2000; Griliches and Mairesse, 1984; and so on) recognizes R&D investment as one production factor in addition to fundamental production factors like labor and capital stock, and has investigated the effect of R&D investment on productivity including Total Factor Productivity (TFP).[1] Also, Keller (2001) shows the role of international spillover effects and the relationship between them. At a firm level, Griffith, Redding, and Van Reenen (2000) provide that R&D leads to innovation and raises the competence of a firm. Crepon, Duguet, and Mairesse (1998) provide evidence for a positive relationship between R&D and innovation outcome as a proxy variable: the patent numbers. They also

[1] Of course, this does not mean that all empirical results provide a positive relationship between R&D and productivity. Even if some case provides a mixed result along with sample period and country, most results indicate the relationship is significantly positive. The useful literature about this discussion is Nadiri (1993) and Zachariadis (2002).

prove a positive relationship between innovation output and productivity growth. In this sense, R&D is essential to improving productivity and therefore is a source of growth for an economy.[2)]

The first contribution of this paper is to empirically measure the economic growth effect of R&D in Korea, extending the period up to 2009. The empirical work utilizes data since the beginning of the publication for the details of R&D investment data by the Ministry Of Education, Science and Technology at 1976. Secondly, this paper is more meaningful in that it investigates the contributions of R&D stocks by sources — private and public R&Ds — as well as a national R&D stock.

2. R&D STOCK AND ECONOMIC GROWTH

The regression of the production function requires the construction of the R&D stock, which is a form of accumulated R&D activity. The accumulation of R&D stock in a particular area requires a time lag for stock formation which includes the accomplishment of R&D projects and the adoption of such efforts in production activities. The R&D stock under an assumed obsolescence rate is fabricated using a perpetual inventory method, with historical R&D expenditures from the initial period onwards. In this case, the procedure of accumulation in R&D stock can be expressed as follows:

$$R_t = \sum_{j=1}^{3} R_{t,j} = \sum_{j=1}^{3} \left\{ RI_{t,j} + \left(1-\delta_j\right) R_{t-1,j} \right\}, \tag{1}$$

where, j indicates financial source for R&D investment, j=1 (public R&D), 2 (private R&D), and 3 (foreign R&D). And R_t and RI_t are overall R&D stock and real R&D investment.

[2)] This paper does not focus on the relationship between TFP and R&D stock; however, the long-term relationship between them is statistically significant. The results can be provided upon request to jwkim@kiet.re.kr.

The accumulation procedure requires the initial R&D stock in a given sample period. The initial R&D stock (R_0) is the sum of the past real R&D investment (RI_{0-i}, $i = 1, ..., \infty$) considering the obsolescence rate (δ). The time lag for the formation of R&D stock is assumed to be one year for convenience.[3)]

Obsolescence implies the devaluation of existing knowledge in economies with technological innovation. In this paper, that obsolescence is assumed to be the depreciation of knowledge, which is known as the process of gradual wear and tear.[4)] For example, Griliches and Mairesse (1984) assumed 15% as the obsolescence rate for reflecting the possible reduction of older R&D over time. Because the intrinsic characteristics of R&D by the three finance sources are often not equal, obsolescence rates might be different across sources.

The initial R&D stock is obtained by summing each initial R&D stock in each finance resource. Each stock by source is calculated using an obsolescence rate and the past real R&D expenditures (investments). All nominal values are transformed into real values as a base of 2005 using the Consumer Price Index. The initial R&D stock will be calculated using the following equation:

$$R_{0,\ j} = \sum_{i=0}^{\infty} RI_{0-i,\ j}(1-\delta_j)^i. \tag{2}$$

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3) The previous studies have applied the various values for the time lags in the formation of R&D stock. Guellec & van Pottelsberghe de la Potterie (2004) use 1 year for complete market acceptance and 2 years for invention. Wang (2007) applies 2 years. Shin (2003) sets the lags of R&D stock formation in public and private R&Ds and as 2 and 3 years. Cho (2004, p. 228) shows the result of the Korea Industrial Technology Association (KOITA). The R&D time lags in Korean manufacturing industries are about 1-2 years. Ha and Lee (2009) also shows the time lags in Korea are 24.17, 12.15, and 5.80 months for basic, applied, and development researches, respectively.

4) I assume that the process of obsolescence shows a continuous pattern. This means that there is no big drop in R&D stocks regardless of R&D expenditure. However, the amount of obsolescence can show a discrete drop in case of a dramatic innovation. Strictly speaking, the obsolescence and depreciation would be different. Stacchetti & Stolyarov (2004) provide that both are differentiated with respect to the two matters: first, obsolescence affects all durables at the same time; second, obsolescence does not happen at a constant rate.

Here, supposing that real R&D investment (RI) from a financial source j grows at the same annual average rate (g_j), the following relationship for the initial R&D stock can be expressed simply:

$$R_{0,\ j} = RI_{0,\ j} \sum_{i=0}^{\infty} \left(1-\delta_j\right)^i \left(1+g_j\right)^{-1} = RI_{0,\ j} \left(1+g_j\right)\left(g_j+\delta_j\right). \tag{3}$$

3. PRODUCTION FUNCTION AND R&D STOCK

The contribution effect of R&D stock can be measured by estimating production function. By assumption, the production function of a national economy follows the Cobb-Douglas specification with:

$$Y_t = A_t L_t^{\alpha} K_{t-1}^{\beta} = \left(R_{t-1}^{\gamma}\right) L_t^{\alpha} K_{t-1}^{1-\alpha}, \tag{4}$$

where α, β, and γ denotes the elasticity of output with respect to labor (L),capital stock (K), and R&D stock (R) for an overall economy. The production process follows a function of current (t) labor as well as capital stock and R&D stock at time t–1, the end of the previous year or the beginning of the current year.[5] Because the CRS production function for the labor and capital stock indicates $\alpha+\beta=1$, here, the positive value of γ guarantees that the R&D-based economy shows an IRS production process.

Now we consider the production function with two types of R&D sources: public R&D stock (R_{PUB}) and private R&D stock (R_{PRI}).[6] Then the production function will be expressed as follows.

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[5] The capital stock value of each period is its value at the end of the previous period; hence, we can say that the amount of capital stock at the last year is same as at the beginning of this year.

[6] Here, foreign R&D stock is not included in the empirical regression because the share of R&D activity by the foreign sector is too low. It will be described in the following “Data” section for detail.

$$Y_t = \left(R_{t-1}^{\gamma}\right) L_t^{\alpha} K_t^{1-\alpha} = \left(R_{PUB,\, t-1}^{\gamma_1} R_{PRI,\, t-1}^{\gamma_2}\right) \cdot L_t^{\alpha} K_t^{1-\alpha}. \tag{5}$$

The decomposition of economic growth $(\Delta Y / Y)$ provides information on the contribution of production factors; that is, the economic growth rate is composed with contributions due to labor, capital stock, private and public R&D stocks.

$$\begin{aligned} \frac{\Delta Y}{Y} &= \left(\frac{\partial Y}{\partial L}\frac{L}{Y}\right)\frac{\Delta L}{L} + \left(\frac{\partial Y}{\partial K}\frac{K}{Y}\right)\frac{\Delta K}{K} + \left(\frac{\partial Y}{\partial R}\frac{R}{Y}\right)\frac{\Delta R}{R} \\ &= \left(\frac{\partial Y}{\partial L}\frac{L}{Y}\right)\frac{\Delta L}{L} + \left(\frac{\partial Y}{\partial K}\frac{K}{Y}\right)\frac{\Delta K}{K} + \left(\frac{\partial Y}{\partial R}\frac{R_{PUB}}{Y}\right)\frac{\Delta R_{PUB}}{R_{PUB}} \\ &\quad + \left(\frac{\partial Y}{\partial R}\frac{R_{PRI}}{Y}\right)\frac{\Delta R_{PRI}}{R_{PRI}}. \end{aligned} \tag{6}$$

The decomposition in equation (6) shows that the contribution of four production factors for economic growth. The contribution of each production factor for economic growth rate is obtained by multiplying its elasticity of output by its change rate. Here, elasticities can be obtained from estimating the production function.

4. DATA

4.1. R&D Investment, R&D Stock, and Obsolescence Rates

The procedure to construct R&D stock using R&D investment data is described in section 2. Even if R&D investment data is available, it is still required to set up the obsolescence rates in this procedure. One of the main features in this paper stems from classifying the R&D investment by sector: public, private, and foreign. Their respective R&D investments are not differentiated from each other with respect to ultimate result, their initiatives may not be equal. By its purpose, public R&D appears to concentrate more

Table 1 R&D Investment for the Purpose of Basic Research Area (by Agent)

(Unit: Billons of won, %)

	2006			2007			2008		
	All	Basic	Share	All	Basic	Share	All	Basic	Share
Public Institute	3,497	717	20.49	4,102	995	24.26	4,653	1,053	22.63
University	2,722	909	33.40	3,334	1,370	41.08	3,845	1,419	36.91
Firm	21,127	2,517	11.92	23,865	2,554	10.70	26,000	3,065	11.79
Total	27,346	4,143	15.15	31,301	4,919	15.71	34,498	5,537	16.05

Notes: a) 'All' and 'Basic' are all R&D investments and the R&D investment for the basic research area, respectively. b) The share is the ratio (%) of R&D investment for a basic research area from all R&D investment.

Sources: MEST (Ministry Of Education, Science and Technology) and KISTEP (Korean Institute of S&T Evaluation and Planning) (2010), 2009 Survey of Research and Development in Korea.

on basic research area when compared to private R&D.[7] In this sense, the outcome from public R&D investment has the characteristic of public good more so than that from private R&D investment; this becomes clear after observing the R&D share of a basic research area in each sector (see table 1). A basic research is necessary for carrying out other types of R&D like an applied research or an experimental development. That is, a basic research becomes more useful because their result can contribute to create value through the combination among their results as well as through the independent use. It enables us to infer that basic research tend to have a

[7] OECD (2002) sorts the R&D into three types: basic research, applied research, and experimental development, based on its purpose. "Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view. Applied research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective. Experimental development is systematic work, drawing on knowledge gained from research and practical experience, that is directed to producing new materials, products and devices; to installing new processes, systems and services; or to improving substantially those already produced or installed."

Table 2 Obsolescence Rates

	Private R&D	Public R&D	Overall R&D
Application in this paper	0.200[a)]	0.125	
Kafouros (2006)	0.200		
Hwang *et al*. (2009)		0.125	
Tsai (2005)	0.200		
Guellec & van Pottelsberghe de la Potterie (2004)			0.150
Shin (2003)	0.227	0.227	
Shin (2004)	0.125	0.125	
Pattel & Soete (1988)			0.125

Note: a) For calculation of R&D stock, foreign R&D is also assumed by following this rate.

longer lifespan than other type researches, an applied research or an experimental development, relatively. The obsolescence rate decreases, as the lifespan of technology is getting lengthening. Hence, this paper imposes different obsolescence rates across the sectors based on past literature (see table 2). The obsolescence rates for public, private and foreign R&D are assumed respectively to be 0.125 (Hwang *et al*., 2009), 0.200, and 0.200 (Kafouros, 2006) in this paper.[8)] This idea is also inspired from Mansfield (1988), who provides that the coefficient for applied research to productivity is 0.07, which is less than 1.49 — coefficient for basic research. The positive effect of R&D on increases in productivity belies the importance of R&D increases. From a long-run perspective, the outcome of basic research tends to have more of a spillover effect on productivities for other sectors; this may affect the extension of the lifespan from new technology. This paper does not test robustness of the following empirical results using alternative obsolescence rates. Hall and Mairesse (1995) show that the choice of depreciation rate in constructing R&D stock does not make much difference to the coefficient estimates for the relationship between R&D and productivity, although it does change the measured R&D stock.

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8) See table 2.

Table 3 R&D Investments by Finance Source

	All		Public		Private		Foreign	
	Million ₩	%	Million ₩	%	Million ₩	%	Million ₩	%
1976	414,794	100	266,871	64.34	146,016	35.20	1,907	0.46
1980	751,498	100	374,313	49.81	363,615	48.39	13,569	1.81
1990	6,208,517	100	987,776	15.91	5,219,120	84.06	1,622	0.03
2000	16,318,079	100	4,497,502	27.56	11,810,861	72.38	9,715	0.06
2005	24,155,414	100	5,877,167	24.33	18,106,814	74.96	171,433	0.71
2006	26,757,049	100	6,489,336	24.25	20,187,214	75.45	80,499	0.30
2007	29,867,726	100	7,802,938	26.12	21,998,275	73.65	66,513	0.22
2008	31,447,675	100	8,431,449	26.81	22,919,508	72.88	96,718	0.31

Sources: R&D investment: Ministry Of Education, Science and Technology. CPI: Bank of Korea.

Table 4 R&D Stocks by Finance Source

	All	Public	Private	Foreign
	%	%	%	%
1976	100.00	72.70	26.92	0.38
1980	100.00	60.01	39.00	0.99
1990	100.00	23.28	76.63	0.09
2000	100.00	32.85	67.08	0.08
2005	100.00	32.12	67.48	0.40
2006	100.00	31.74	67.90	0.37
2007	100.00	31.85	67.83	0.32
2008	100.00	32.15	67.54	0.31

Sources: R&D investment: Ministry Of Education, Science & Technology. CPI: Bank of Korea.

As the economy has recognized the importance of new technology, R&D investment has been increased (see table 3). The outcome is high growth in R&D stocks — overall 7,000% — from 1976 to 2008. During the 1970s, the government took the lead in R&D activity; however, after the 1980s, privately-sourced R&D investment became greater than public R&D investment. During the 2000s, the share of R&D investments from each source seems to be stable. In particular, the share of private R&D investment after the year 2000 has fluctuated at a range of 72-76%. This shows that the structure of R&D investment has become 1:3, government to private. The share of foreign R&D activity has been relatively low, less than 1% with respect to the investment and stock, after 1980. Based on this reason, foreign R&D is used in calculations of overall R&D stock, but not applied to the regression.[9)]

4.2. Other Production Factors

As mentioned above, the estimation of production function requires the traditional production factors such as labor and capital inputs as well as R&D stock. For labor, the total annual work hours are applied using the survey on the Economic Active Population in Statistics Korea. Also capital stock is calculated using the net capital stock from the database of the National Wealth Statistics in Statistics Korea. It has been transformed into a continuous series using a benchmark-year method up to the year 1997, and using a perpetual inventory method after. The reason for using two different methods is due to the discontinuity of official data: up to 1997, data on national wealth was only announced every 10 years. After 1997, Statistics Korea started reporting an estimated annual net capital stock. All values are transformed into a constant price for the year 2005 using data of investment deflators from the Bank of Korea.

[9)] In addition to that, the inclusion of foreign R&D stock in the regression as an explanatory variable may bring about a multicollinearity problem. R&D Stocks by Finance Source are reported in table 4.

5. EMPIRICAL MODEL AND RESULTS

Most of the time, the production function is estimated in order to calculate the contribution of R&D stock for economic growth, based on the procedure outlined in this paper. The basic representation for an empirical model starts from equation (5). Taking a natural logarithm into equation (5), the two empirical models can be expressed as the following equations (7) and (8). Those equations show a type of co-integrating relationship known as the cointegration representation of Engle-Granger (1987). Here, the cointegration test is required whether or not those equations show a true co-integrating relationship, which is a long-run relationship among variables.

<Model 1>

$$\ln(y_t) = a_0 + \alpha \ln(k_t) + \gamma \ln(R_{t-1}) + \kappa_1 D_1 + \kappa_2 D_2, \quad (7)$$

<Model 2>

$$\ln(y_t) = a_0 + \alpha \ln(k_t) + \gamma_1 \ln(R_{PUB,\, t-1}) + \gamma_2 \ln(R_{PRI,\, t-1}) + \kappa_1 D_1 + \kappa_2 D_2, \quad (8)$$

where, D_{1980} and D_{1998} are dummy variables to consider 1980 and 1990, both of which showed a negative economic growth rate. The Korean economy suffered from the Oil Shock of 1980 and Financial Crisis of 1998. R_{PUB} and R_{PRI} are public and private R&D stocks. Foreign R&D is not considered as an explanatory variable in the regression because its share is too low.

Before the estimation, an Engle-Granger cointegration test is performed. At the start, all variables should be non-stationary. Then, we can say that each equation shows the cointegration when the liner combination of the variables, which is residual, is statistically stationary in each equation. According to the result of a stationary test for the variables in each equation, all variables are shown as non-stationary series by a Dickey-Fuller GLS test[10)] at the 5% significance level (see table 5). Also, an Engle-Granger

[10)] The test is proposed by Elliot, Rothenberg, and Stock (1996). It is a modification of

Table 5　Unit Root Test of the Variables in Model 1 and Model 2

	Dickey-Duller GLS	
	Level	First Difference
$\ln(y_t)$	–1.3005	–6.7566***
$\ln(k_t)$	–1.7024	–3,3625**
$\ln(R_{t-1})$	–1.6810	–3.6297**
$\ln(R_{PUB,\,t-1})$	–0.0962	–2.2103**
$\ln(R_{PRI,\,t-1})$	–0.9468	–5.2936***

Notes: a) The null hypothesis is the existence of a unit root in each variable. b) *, **, and *** are significance levels of 10%, 5%, and 1%. c) For all variables except public R&D stock, the basic assumption is to have intercept and trend. Public R&D stock is assumed to have an intercept but no trend.

Table 6　Cointegration Tests in Model 1 and Model 2

	Model 1	Model 2
Engle-Granger Cointegration Test[a)]		
Cointegration Test Statistic[b)]	–1.9937**	2.6993***
Johansen Cointegration Test for Model 1		
Null Hypothesis	Trace Statistics	*P*-value
C=0***	50.6139	0.0071
$C \leq 1$	15.1580	0.5614
$C \leq 2$	2.9402	0.8836

Notes: a) All cointegration tests are assumed each one has an intercept, and use the Dickey-Duller GLS. b) The null hypothesis is non-existence of cointegration. c) *, **, and *** are significance levels of 10%, 5%, and 1%.

Also, the results of a Johansen (1991 and 1995) cointegration test also support the existence of the co-integrating vector (see table 6).

Augmented Dickey-Fuller (1979) test. The key of this test is to detrend data before test regression.

Table 7 Estimation of R&D-based Production Function

	Model 1		Model 2
	OLS &HAC	Cochrane-Orcutt	OLS using Model 1
a_0	–0.4194 (–0.3812)	0.8710 (0.6429)	1.080*** (7.0337)
α	0.2583*** (3.3224)	0.3595*** (3.8108)	d)
γ	0.2164*** (4.7129)	0.1656*** (2.8931)c)	e)
γ_1			0.0910*** (3.4508)c)
γ_2			0.0695*** (3.6544)c)
κ_1	–0.0496* (0.0729)	–0.1112*** (–4.8213)	–0.1093** (–2.2032)
κ_2	–0.1029*** (–4.4995)	–0.0820*** (–3.3367)	–0.0629 (–1.2137)
R^2	0.9925	0.9761	0.9919
D-W	0.5358	1.6192	

Notes: a) *, **, and *** are significance levels of 10%, 5%, and 1%. b) D-W is the Durbin-Watson statistic. c) The standard errors for γ, γ_1, and γ_2 are 0.0572, 0.0263, and 0.0190, respectively. d) Assumes the coefficient values, 0.3595, which is estimated from Cochrane-Orcutt in Model 1. e) Assumes the coefficient values, 0.1656, which is estimated from Cochrane-Orcutt in Model 1.

Even if the existence of a cointegrating relationship is supported by the above test, the direct OLS (Ordinary Least Squares) estimation brings the following two-estimation problem in models 1 and 2. It is because of the autocorrelation problem[11] in both models and moreover the multicollinearity[12] arising from introducing both R&D stocks in model 2. Those problems affect the reliability of coefficients estimated. Therefore, the estimation plan is composed of two steps: first, model 1 is estimated using the heteroskedasticity-autocorrelation consistent (HAC) covariance matrix (Newey and West, 1987) and the Cochrane-Orcutt (1949) procedure. The Cochrane-Orcutt procedure is known as one econometric method to

[11] In the table 7, the first OLS estimation shows a low value of Durbin-Watson statistics. It is the evidence of autocorrelation.

[12] When I estimate all coefficients in equation (8) directly, the coefficient (γ) for capital becomes unstable compared with that in equation (7).

eliminate the autocorrelation with Prais-Winsten (1954). The coefficient of autocorrelation coefficient (ρ) is calculated using 'ρ=1–0.5·DW', where DW is a Durbin-Watson statistic in the simple OLS estimation of the equation (7). Then, we estimate again for model 1 after taking the autocorrelation-coefficient-weighted first difference of equation (7).[13] The result does not show an autocorrelation problem.

Second, assuming the capital elasticity values (γ) of output already estimated in the first step[14], model 2 is estimated. In this second step, the coefficient attained using the Cochrane-Orcutt method is selected because the method generates the more reasonable coefficients for capital and labor, along with the characteristics of data. The data for labor and capital is ascertained for the purpose of total factor productivity using the growth accounting theory, which imposes the CRS for labor and capital. Based on the data construction before estimating this model, the share of labor income has been about 65% each year. This means that the share of capital income must be close to 35% (=1–0.65).[15]

All production factor elasticities of output are statistically significant at a level of 5% (see table 8). In particular, the capital (per labor) elasticity of output is 0.3595, which means that the labor elasticity of output is about 0.6405 (=1–0.3595). Also, the overall R&D elasticity of output, γ, is 0.1656. The private and public R&D elasticities of output are 0.0695 (γ_1) and 0.0910 (γ_2), respectively. Even if the overall R&D elasticity (γ) is greater than both sub-R&D elasticities, the value of γ is not statistically different with γ_1 or γ_2 because the 95% confidence intervals of the coefficients are overlapped.[16]

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13) Refer Jonston and DiNardo (1996).

14) A coefficient using Cochrane-Orcutt method is applied. Even if the coefficient estimated in OLS-HAC method were applied, the signs and significances of both R&D stocks are not changed.

15) The share of labor income is calculated using the compensation ratio of employees announced by BOK and labor statistics announced by Statistics Korea. The main assumption for calculation is that the compensation of nonwage workers is half of that of wage workers (employees).

16) The 95% confidence intervals are $0.0512 \le \gamma \le 0.2800$, $0.0315 \le \gamma_1 \le 0.1075$, and $0.0384 \le \gamma_2 \le 0.1436$.

Table 8 Contribution of Production Factors to Economic Growth

	Y	*L*	*K*	*R&D*		
					Public	Private
Growth Rate	6.66	1.42	10.01	14.54	11.65	17.88
Elasticity	1	0.6405	0.3595	0.1656	0.0910	0.0695
Contribution Rate	100	13.12	52.07	34.81	16.03	18.78

Notes: a) The growth rate and contribution are based on percentage. b) The growth rate is the annual average growth rate during the period considered.

Now, the contribution effect of R&D stock to economic growth can be completed using the elasticities and growth rates of each variable. For output and labor, the growth rates are calculated from 1977 to 2009, which considers the effective sample period of the above estimation. Also, the growth rates of capital and R&D stocks are calculated from 1976 to 2008 in order to consider production specifications designed in this paper; that is, by assumption, the production at time *t* is not merely a function of current labor, but also a function of the past variables at time *t*–1, like R&D and capital stocks.

Based on the empirical result, the contribution shares of traditional production factors — labor and capital — are 13.12% and 52.07%, relatively, and the contribution share of overall R&D stock is 34.81% (see table 8).[17) Compared with the empirical results of the past literature, these contributions appear to be reasonable. This contribution rate of R&D is similar with the past literatures including Ha (2005) and Shin (2004) which are shown in (table 9).

[17) The international comparison of the R&D contributions to the economic growth is not the main focus in this paper. However, according to the Blue House briefing presented by STEPI (2007), the contribution rate of R&D activities to economic growth rate in Korea is 30.6% during 1971-2004. This rate is greater than U.S. (20.8%), Canada (16.0%), and Italy (24.3), but is less than Japan (48.8%). Our result for that in Korea is 34.81% during 1976-2009. STEPI, *International Comparison for the Contribution of R&D Investment to Economic Growth*, 2007.

Table 9 Contribution of Production Factors to Economic Growth (Past Literatures)

	Period	Capital	Labor	R&D	Others
Shin (2004)	1980-2002	50.7	19.2	28.1	
Ha (2005)	1991-2000	46.6	18.1	10.9	24.4

Note: In Ha (2005), 'Labor' indicates labor supply and 'Others' includes human capital and some TFP effect.

That is, Shin (2004) suggests the R&D contribution rate as 28.1%. Also even if Ha (2005) discriminates R&D effect from other effects which include human capital and some TFP effect, the latter effect can be considered as a result of R&D activities. Aggregation of the both effects is 35.3%. In addition to the past literatures, this paper estimates the contribution of two sourced R&D stocks for economic growth. The growth contributions of each R&D stocks in public and private sectors are estimated as 16.03% and 18.78%.

6. CONCLUSION

This paper investigates the contribution effect of R&D stock for economic growth using the Cobb-Douglas production function during the years 1976-2009. The empirical sample period is chosen along with availability of the R&D data by investor. The empirical work starts from estimating R&D-based production function, which is CRS for the traditional production factors — labor and capital — but can be IRS only in case of a positive R&D elasticity of output.

The empirical procedure to estimate the contribution of R&D stock to economic growth is simple: first, the R&D-based production function is estimated, then the decomposition of the economic growth enables us to indentify contributions by production factor.

Based on the empirical results, the traditional production factors — labor and capital — contribute about 65% to economic growth. Also, the contribution ratio of R&D stock to economic growth is about 35%. In detail, public and private R&D stocks account for economic growth of about 16% and 19%, respectively. These findings suggest every single R&D activity regardless R&D sources is necessary to maintain the economic growth.

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