R&D Expenditure, International Trade and Economic Growth: Korea's Experience*

Myung-Hoon Yi**, Jai-Shin Mah***

Abstract

Purpose – The purpose of this research is to investigate whether Korea's economic growth can be explained by the endogenous growth theory. Specifically, we test whether R&D expenditure has a positive and significant effect on the economic growth.

Research design, data, and methodology – We hypothesize that R&D expenditure has a positive effect on the economic growth after adding control variables in the growth equation. Korean annual data from 1963 to 2011 from Science and Technology Annual of the Ministry of Education, Science and Technology, the Bank of Korea, etc. are used. We estimate the growth equation by GMM in addition to OLS.

Results – We found that R&D expenditure has a positive and significant effect on the economic growth after adding the ratio of investment to GDP, the ratio of FDI to GDP, the ratio of government expenditure to GDP, inflation and the ratio of trade openness to GDP as control variables in the growth equation.

Conclusions – Our results show that Korea's rapid economic growth for the past five decades can be explained by the R&D-based endogenous economic growth theory. Our results suggest that the policy attention of the Korean government be paid to R&D promotion.

Keywords: R&D Expenditure, Trade, Economic growth, Generalized method of moments (GMM).

JEL Classifications: C22, O40.

1. Introduction

1.1. Purpose and Background

The Korean economy is noteworthy in the sense of recording very high economic growth rates for the past five decades and transforming from an agrarian society to a knowledge-based economy. Although Korea's industrial policy focused on promoting the heavy and chemical industries during the 1970s, its focus shifted to promoting R&D activities later. It established science-specialized research institutes, science parks, and science-specialized academic institutions. R&D expenditure increased significantly and various tax incentives were provided to firms' R&D activities (Mah, 2007 Jung & Mah, 2013). Due to the lively R&D activities and the consequent innovations, technology-intensive industries such as semiconductors, mobile handsets and automobiles have developed rapidly and now lead Korea's exports, although, according to Seo et al. (2012), the progress of financialization in Korea had a negative effect on R&D investment after the 1997–98 Asian financial crisis.

Since the Korean government has pursued R&D promotion together with trade liberalization policies actively and the Korean economy has recorded rapid economic growth, Korea's experience appears to be a good case for testing the endogenous economic growth theory which emphasizes the role of R&D and international trade in promoting productivity. Therefore, the current paper uses data for Korea since the beginning of the rapid economic growth and tests whether Korea's economic growth can be explained by the endogenous growth theory. This paper is different from the other preceding works examining the effect of R&D expenditure on economic growth in Korea in the sense that, unlike the latter, the former applies rigorous time series techniques such as GMM to a model including both R&D expenditure and globalization factors which may affect economic growth of the outward-oriented Korean economy significantly.

We formed the structure of the rest of this paper as follows. The literature review on the effect of R&D expenditure on economic growth is provided in Section 2. Sections 3 explains the model to be estimated, econometric methodology and data, respectively. Section 4 explains empirical results. Conclusions are provided in Section 5.

2. Literature Review

Economic growth has attracted many researchers' attention. For instance, Tambi (2015) reviews various aspects of economic growth of developing countries. The first wave of endogenous

---

** Corresponding Author, Professor, Department of Economics, Myongji University, Seoul, Korea. E-mail: yimh@mju.ac.kr

*** Professor, Division of International Studies, Ewha Womans University, Seoul, Korea. E-mail: jsmah@ewha.ac.kr

growth models, the AK models, focused on constant returns to broadly defined capital as the device for generating endogenous growth. The prediction that a permanent increase in the investment rate generates a permanent increase in growth is an essential feature of the AK-type models of endogenous growth. Partly due to dissatisfaction with the empirical performance of the AK models, the focus of the endogenous growth literature has shifted to the R&D-based model that explains long-run economic growth by focusing on technological progress and R&D (Jones, 1995).

Some empirical works have tested the R&D-based endogenous economic growth models. Young (1998) showed that the share of R&D investment in total economy or share of researchers in the population should be used to test the R&D-based endogenous economic growth models. Applying GMM method to the data for the US and Germany, Gong et al. (2004) found that, for the R&D-based endogenous growth model, scale effects do not exist. That is, increase in the amount of R&D expenditure *per se* does not lead to rise in economic growth rate. Zachariadis (2004) used aggregate and manufacturing-sector data across ten advanced OECD countries. He considered the role of international trade as well as R&D intensity defined as R&D expenditure divided by GDP to explain productivity growth. He found that increasing R&D intensity by one percentage point increases output growth by about 0.11 percentage points.

Griffith et al. (2004) also explored the idea that in addition to stimulating innovation, R&D enhances technology transfer, i.e. absorptive capacity. They tested it with industry panel data composed of twelve OECD countries. They found that R&D expenditure has an effect on technological catch-up and innovation. That is, the lagged terms of R&D intensity were revealed to be positive and significant in determining the total factor productivity (TFP). Meanwhile, there was only a small effect of international trade. Ulku (2007) used macro level patent and R&D data from 26 OECD and 15 non-OECD countries to examine the endogenous growth predictions that a share increase of researchers in the labor force increases innovation and innovation raises per capita output. Ulku's (2007) analysis showed that an increase in the ratio of researchers to total labor force increased innovation only in the large market OECD countries, including the G7 countries.

Bravo-Ortega & Marin (2011) noticed that a significant number of studies ignored the potential problem arising from simultaneity and reverse causality between R&D expenditure and TFP. That is, since TFP shock may affect income and then R&D spending, we can also think of causality from TFP to R&D spending. Applying the system GMM estimation method to a 65 developed and developing country panel, Bravo-Ortega & Marin (2011) showed that lagged TFP, terms of trade and per capita R&D expenditure contributed significantly to TFP, while neither trade/GDP ratio nor FDI/GDP ratio affects it.

Using U.S. firm-level data, Chun et al. (2014) showed that firms' technological heterogeneity could further increase the long-run growth potential of an economy through facilitating R&D financing. In this manner, the empirical works reviewed so far

have in general shown that the R&D-based economic growth models are supported in high-income OECD countries. Many of those empirical works in the endogenous growth literature found that R&D is more important than trade liberalization in influencing productivity. It appears that there has been limited evidence on the tests of the R&D-based endogenous growth theory applied to non-high-income OECD countries.

3. Methodology

3.1. Model

Romer's (1990) R&D-type endogenous growth model postulates a production function as follows:

$$y_t = A_t f(k_t) \tag{1}$$

where y_t is the real per capita GDP, A_t is the level of technology, and k_t is the real per capita capital. A_t is assumed to be determined by the level of R&D expenditure chosen by the economic agent's optimizing behavior. As R&D expenditure increases, the level of technology (A_t) increases, and so y_t also increases.

We hypothesize that R&D expenditure has a positive effect on the economic growth after adding control variables in the growth equation. Following Barro (1997, 2013) and Choi & Yi (2009), we include three control variables - the ratio of gross domestic investment to GDP, the ratio of government expenditure to GDP and the inflation rate. Additionally, we include the ratio of FDI to GDP and the ratio of the trade openness to GDP, reflecting the progress of globalization for the past several decades in Korea. For instance, Mago *et al.* (2013) reveals the positive effect of globalization on economic growth of Zimbabwe. For estimation, we set the growth equation as follows:

$$YG_t = \beta_0 + \beta_1 R\&D_t + \beta_2 Inv_t + \beta_3 FDI_t + \beta_4 Gov_t + \beta_5 Inf_t + \beta_6 Trade_t + u_t \tag{2}$$

where YG_t is the real per capita GDP growth rate at year t $R\&D$ is the ratio of R&D expenditure to GDP; Inv is the ratio of gross domestic investment to GDP FDI is the ratio of FDI inflows to GDP Gov is the ratio of government expenditure to GDP Inf is the inflation rate; $Trade$ is the trade dependence ratio defined as total exports and imports divided by GDP u_t is an error term.

3.2. Econometric Methodology

We estimate equation (2) by GMM in addition to OLS. According to Hansen (1982), GMM estimation can be applied to the orthogonality condition as follows,

$$E_{t-1}[u_t(\beta)] = 0 \tag{3}$$

where $u_t = YG_t - [\beta_0 + \beta_1 R\&D_t + \beta_2 Inv_t + \beta_3 FDI_t + \beta_4 Gov_t + \beta_5 Inf_t + \beta_6 Trade_t]$, $\beta = (\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6,)$, t = 1, 2, ... , T, and E_{t-1} is expectation operation conditional on information set(I_{t-1}) at time t-1. Conditional expectation equation (3) can be expressed as unconditional expectation equation (4) under rational expectations hypothesis,

$$E[u_t(\beta) \otimes Z_{t-1}] = E[f(\beta)] = 0 \tag{4}$$

where Z_{t-1} is a set of instrumental variables at time t-1, $Z_{t-1} \in I_{t-1}$, and $\otimes$ is the Kronecker product. The sample moment of equation (4) can be written as $g_T(\beta)$.

To get the GMM estimator of β, we find the estimated coefficients of β, which minimizes the quadratic distance function as follows,

$$\beta^* = \arg\min g_T{}'(\beta) W_T g_T(\beta) \tag{5}$$

where W_T is a weighting matrix. GMM estimator can be obtained by two step procedures. First, we use a suboptimal choice of W_T, $W_T = I$ (identity matrix), and get the inefficient estimators. Second, we substitute these inefficient estimators into equation (5), and get the efficient estimators.

When the number of unconditional moment restrictions, sf where s is the number of equations and f is the number of instruments, is greater than the number of parameter, h, there are (sf-h) linearly independent orthogonality conditions which are not equal to zero in estimation, but should be close to zero if the model is well specified. Hansen (1982) showed that J-statistic, $Tg_T{}'(\beta^*) W_T g_T(\beta^*)$, is distributed as a chi-square with (sf-h) degree of freedom. Hence, we can test the model's over-identifying restrictions. This test indicates how far the remaining (sf-h) sample moments are from the hypothesized values of zero.

The GMM estimation does not require the specification of the random variables' underlying distribution. The GMM estimators are consistent and efficient even if the error terms are heteroskedastic or serially correlated.

3.3. Data

We used Korean annual data from 1963 to 2011 to estimate equation (2). R&D data are from *Science and Technology Annual* of the Ministry of Education, Science and Technology. FDI data are taken from the Ministry of Trade, Industry and Energy (http://www.motie.go.kr). Data for real per capita GDP growth rate, the ratio of gross domestic investment to GDP, the ratio of government expenditure to GDP, the inflation rate calculated from GDP deflator, and the trade dependence ratio are from the Bank of Korea (http://ecos.bok.or.kr).

<Table 1> provides the changing tendency of selected important variables relating to economic growth of Korea during 1963-2011. R&D expenditure divided by GDP rose from less than 1% until 1981 to between 2 and 3%during 1992-2006 and then to 3.6% during 2007-2011. Per capita real GDP growth rate had been in general higher than 6%until the mid-1990s, while it decreased to lower than 5% since the late 1990s. Although the trade dependence ratio had been lower than 50%during the 1960s, it rose sharply to over 60% during the 1970s and the 1980s. Although it fell somewhat during the mid-1990s, it increased again since the late 1990s and reached even over 100% during 2007-2011.

The ratio of investment divided by GDP was as low as 15% in the early 1960s meanwhile, it increased significantly since then. It continued to record between 28 and 36% since the late 1970s. Although the ratio of FDI inflows divided by GDP continued to be in general lower than 1% until the mid-1990s, it rose sharply since 1998, when the government began to attract FDI inflows actively. The ratio of government expenditure divided by GDP continued to rise gradually. It increased particularly since the 2000s, reaching 15.3%during 2007-2011.

<Table 1> Tendency of Selected Macroeconomic Variables, 1963-2011

(%)

Years	YG	R&D	Trade	Inv	FDI	Gov
1963-1966	6.4	.3	24.8	15.1	.4	9.8
1967-1971	7.6	.4	40.4	24.1	.7	10.4
1972-1976	8.4	.4	60.8	24.8	1.1	10.6
1977-1981	5.6	.6	70.4	30.8	.3	10.6
1982-1986	8.7	1.2	73.2	28.3	.4	11.6
1987-1991	8.9	1.8	63.0	32.7	.5	11.3
1992-1996	6.3	2.2	56.4	36.0	.4	11.6
1997-2001	3.9	2.3	73.6	30.3	2.5	12.2
2002-2006	4.3	2.7	75.4	28.9	1.4	13.5
2007-2011	2.9	3.6	102.7	28.5	1.2	15.3

<Table 2> R&D and Economic Growth: Total Sample [a, e]

	(a)[b] OLS	(b)[b] OLS	(c)[c] GMM	(d)[d] GMM
Constant	0.101 (4.825)	7.225* (4.241)	29.548*** (6.807)	42.344*** (12.338)
R&D	3.881** (1.586)	2.881*** (0.945)	3.379** (1.619)	3.136** (1.247)
Inv	-0.066 (0.092)	0.014 (0.081)	-0.346** (0.134)	-0.623*** (0.230)
FDI	1.443*** (0.438)	0.947** (0.446)	-11.288*** (2.686)	-7.619*** (1.957)
Gov	0.502 (0.381)	-0.434 (0.491)	-0.974** (0.435)	-1.514** (0.562)
Inf	0.032 (0.058)		0.154* (0.084)	
Trade		0.065** (0.024)		0.016 (0.041)
D.W.	2.202	2.285		
p-value J-statistic			0.171	0.122

Notes:
a. ***denotes the 1% significance level, ** denotes the 5% significance level, and, *denotes the 5% significance level. Standard errors are in parentheses.
b. Newey and West's (1987) heteroscedasticity and autocorrelation consistent covariance matrix is used for standard errors.
c. Instrumental variables = {constant, YG_{t-i}, $R\&D_{t-i}$, Inv_{t-i}, FDI_{t-i}, Gov_{t-i}, Inf_{t-i}, i = 1, 2, 3}
d. Instrumental variables = {constant, YG_{t-i}, $R\&D_{t-i}$, Inv_{t-i}, FDI_{t-i}, Gov_{t-i}, $Trade_{t-i}$, i = 1, 2}
e. Total sample period: 1963-2011

4. Results

<Table 2> shows the regression results for total sample 1963-2011. We estimated equation (2) by OLS[1] and GMM method. According to the benchmark OLS regression (column (a) in Table 2), the estimated coefficient of *R&D* is 3.881 and significant at the 5% level. This result supports our hypothesis that R&D expenditure has a positive effect on the economic growth. The estimated coefficient of *Inv* is insignificant at any reasonable level of significance. The estimated coefficient of *FDI* is 1.443 and significant at the 1% level. The estimated coefficients of *Gov* and *Inf* are insignificant. In column (b) in Table 2, the estimated coefficient of *R&D* is 2.881 and significant at the 1% level. This result also supports the positive relationship between R&D expenditures and economic growth. Additionally, the estimated coefficient of *Trade* is 0.065 and significant at the 5% level.

In equation (2), the dependent variable, economic growth, may affect such explanatory variables as R&D ratio, investment ratio, the government expenditure ratio, and the trade dependence ratio. So to solve any possible endogeneity problem in the

---

1 In OLS estimation, trend and trend squared are included in the explanatory variables to correct for serial correlation of error terms, and dummy variables for the years of negative growth rates, 1980, 1998 and 2009 are included in the explanatory variables to mitigate outlier problems in the data. Detailed OLS results for these extra variables are available upon request.

explanatory variables, we re-estimated equation (2) by GMM (columns (c) and (d) in <Table 2>). The estimated coefficients of R&D are 3.379 and 3.136, respectively, all significant at the 5% level. This result also supports our hypothesis that R&D expenditure has a positive effect on the economic growth.

Contrary to the results of OLS estimation, the estimated coefficients of *Inv* estimated by GMM are negative and significant at the 5% level. These mixed results may reflect the measurement error problem of investment data. The estimated coefficients of *FDI* are negative and significant at the 1% level, which is contrary to the OLS estimation results. The negative effect of FDI on economic growth can be explained by the fact that FDI flows into Korea increased significantly since 1998, when the government began to attract FDI actively to cope with the economic crisis. The Korean economy has shown relatively low economic growth rates since then.

In columns (c) and (d) in Table 2, the estimated coefficients of *Gov* are −0.974 and −1.514, respectively, all significant at the 5% level. This means that the government expenditures crowds out private investment, negatively affecting economic growth. The estimated coefficient of *Inf* is 0.154, and significant at the 10% level. *Trade* is revealed to be not significant at any reasonable level of significance. Hansen's (1982) *J*-statistics have *p*-values of 0.171 and 0.122, which means that the data support the model's overidentifying restrictions. The null hypothesis the model is well specified is not rejected at the 10% significance level.

<Table 3> R&D and Economic Growth: Sub-Sample [a, e]

	(a) [b] OLS	(b) [b] OLS	(c) [c] GMM	(d) [d] GMM
Constant	25.714** (9.642)	19.138* (9.167)	25.333*** (0.963)	-27.866** (12.821)
R&D	11.533* (6.498)	14.035* (6.928)	1.727*** (0.275)	1.535* (0.751)
Inv	-0.249 (0.341)	-0.304 (0.316)	-0.079** (0.031)	0.371* (0.190)
FDI	-1.541 (1.812)	-1.042 (1.906)	-1.350*** (0.376)	5.686** (2.028)
Gov	-2.040** (0.701)	-1.560 (1.004)	-1.279*** (0.094)	2.489* (1.271)
Inf	-0.107 (0.106)		-0.081*** (0.013)	
Trade		0.017 (0.126)		-0.081 (0.061)
D.W.	2.254	2.203		
p-value J-statistic			0.265	0.116

Notes:
a. ***denotes the 1% significance level, ** denotes the 5% significance level, and, * denotes the 5% significance level. Standard errors are in parentheses.
b. Newey and West's (1987) heteroscedasticity and autocorrelation consistent covariance matrix is used for standard errors.
c. Instrumental variables = {constant, YG_{t-i}, $R\&D_{t-i}$, Inv_{t-i}, FDI_{t-i}, Gov_{t-i}, Inf_{t-i}, i = 1, 2, 3}
d. Instrumental variables = {constant, YG_{t-i}, $R\&D_{t-i}$, Inv_{t-i}, FDI_{t-i}, Gov_{t-i}, $Trade_{t-i}$, i = 1, 2}
e. Sub-sample period: 1963-1988

<Table 3> shows the regression results for sub-sample, 1963-1988, when the Korean economy showed very rapid high economic growth. Afterwards, low economic growth is a dominant phenomenon. We would like to examine whether R&D expenditure was more or less important in the high economic growth period.

According to the benchmark OLS regression (column (a) in <Table 3>), the estimated coefficient of *R&D* is 11.533 and significant at the 10% level. The estimated coefficients of *Inv, FDI* and *Inf* are insignificant at any reasonable level of significance. The estimated coefficient of *Gov* is -2.040 and significant at the 5% level. In column (b) in <Table 3>, the estimated coefficient of R&D is 14.035 and significant at the 10% level. All other explanatory variables including *Trade* are insignificant. The results reported in columns (a) and (b) support the positive relationship between R&D expenditures and economic growth.

We re-estimated equation (2) by GMM (columns (c) and (d) in <Table 3>). The estimated coefficients of *R&D* are 1.727 and 1.535, which are statistically significant at the 1% and 10% level, respectively. This result also supports our hypothesis that R&D expenditure has a positive effect on the economic growth. The estimated coefficients of *Inv* estimated by GMM are -0.079 and 0.371, and significant at the 5% and 10% level, respectively. These mixed results may reflect the measurement error problem of investment data. The estimated coefficients of *FDI* are -1.350 and 5.686, and which are statistically significant at the 1% and 5% level, respectively.

In columns (c) and (d) in <Table 3>, the estimated co-efficients of Gov are −1.279 and 2.489, significant at the 1% and 10% level, respectively. The estimated coefficient of *Inf* is -0.081 and significant at the 1% level. *Trade* is revealed to be not significant at any reasonable level of significance. Hansen's (1982) *J*-statistics have *p*-values of 0.265 and 0.116, which means that the data support the model's overidentifying restrictions. The null hypothesis that the model is well specified is not rejected at the 10% significance level.

5. Conclusions

According to the endogenous growth theory, R&D expenditures and trade liberalization positively affect economic growth. Since the policy attention of the Korean government has been paid to R&D promotion as well as trade liberalization, we hypothesize that high R&D expenditure together with trade liberalization have led to rapid economic growth in Korea. This paper is different from the other works testing the effect of R&D expenditure on economic growth in Korea in the sense that the current paper applies rigorous time series techniques to a model comprising both R&D expenditure and globalization-related variables, among others.

Using Korean annual data from 1963 to 2011, we confirm our hypothesis that R&D expenditure increased economic growth significantly. Meanwhile, there is no convincing evidence of trade liberalization *per se* accounting for economic growth.

We re-estimate the growth equation for the sub-sample period, when Korean economy showed very rapid economic growth. Regardless of the estimation method, the positive and significant contribution of R&D expenditure on economic growth is reconfirmed. Overall, Korea's rapid economic growth for the past half century appears to be explained by the R&D-based endogenous growth theory.

The results are quite robust across different explanatory variables, estimation methods and sample periods. Unlike the positive and significant contribution of R&D expenditure, trade dependence ratio is revealed to be in general not significant in raising economic growth rate of Korea, which is consistent with the results reported in Griffith et al. (2004) and Bravo-Ortega & Marin (2011), for instance. There is mixed evidence on the impact of FDI inflows on economic growth.

References

Barro, R. J. (1997). Determinants of economic growth: *A Cross-Country Empirical Study*. Cambridge, MA: MIT Press.

Barro, R. J. (2013). Inflation and economic growth. *Annals of Finance and Economics*, 14(1), 121–144.

Bravo-Ortega, C., & Marin, A. G. (2011). R&D and Productivity: A Two Way Avenue?. *World Development*, 39(7), 1090-1107.

Choi, C., & Yi, M. H. (2009). The effect of the Internet on economic growth: evidence from cross-country panel data. *Economics Letters*, 105(1), 39–41.

Chun, H., Ha, J., & Kim, J. W. (2014). Firm heterogeneity, R&D, and economic growth. *Economic Modelling*, 36(1), 149-156.

Gong, G., Greiner, A., & Semmler, W. (2004). Endogenous growth: Estimating the Romer model for the US and Germany. *Oxford Bulletin of Economics and Statistics*, 66(2), 147-164.

Griffith, R., Redding, S., & Van Reenen, J. (2004). Mapping the two faces of R&D: productivity growth in a panel of OECD Industries. *Review of Economics and Statistics*, 86(4), 883-895.

Hansen, L. P. (1982). Large sample properties of generalized method of moments estimators. *Econometrica*, 50(4), 1029–1054.

Jones, I. C. (1995). Time series tests of endogenous growth models. *Quarterly Journal of Economics*, 110(2), 495-525.

Jung, J., & Mah, J. S. (2013). R&D Policies of Korea and Their Implications for Developing Countries. *Science, Technology and Society*, 18(2), 165-188.

Mago, S., Masasa, G., & Matunhu, J. (2013). The impact of globalization on business and economic development in Zimbabwe. *East Asian Journal of Business Management*, 3(2), 31-37.

Mah, J. S. (2007). Industrial policy and economic development: Korea's experience. *Journal of Economic Issues*, 41(1), 77–92.

Newey, W. K., & West, K. D. (1987). A simple, positive semi-definite, heteroscedasticity and autocorrelation consistent covariance matrix. *Econometrica*, 55(3), 703–708.

Romer, P. M. (1990). Endogenous technical change. *Journal of Political Economy*, 98(5), S71–S101.

Seo, H. J., Kim, H. S., & Kim, Y. C. (2012). Financialization and the slowdown in Korean firms' R&D investment. *Asian Economic Papers*, 11(3), 35-49.

Tambi, M. (2015). Economic growth, crisis, and recovery in Cameroon: A Literature Review. *International Journal of Industrial Distribution & Business*, 6(1), 5-15.

Ulku, H. (2007). R&D, innovation and output: evidence from OECD and non-OECD countries. *Applied Economics*, 39(3), 291–307.

Young, A. (1998). Growth without scale effects. *Journal of Political Economy*, 106(1), 41–63.

Zachariadis, M. (2004). R&D-induced growth in the OECD?. *Review of Development Economics*, 8(3), 423–439.