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PAPER

R&D Spillovers and Total Factor Productivity in South Korea with ARDL Approach

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Abstract This study aims to examine the impact of R&D spillovers on the South Korean total factor productivity (TFP) using the Autoregressive Distributed Lag (ARDL) estimation technique. Using data from the period 1985-2005, the results show that the domestic research and development (R&D) expenditure and foreign direct investment (FDI) have positive impact on the productivity growth in South Korea, in the long run. However, in the short run, the domestic R&D and the imports of goods and services have significant positive impact on the country's TFP.

Keywords R&D spillovers - Total Factor Productivity - Research & Development - South Korea - ARDL

JEL Classification O31 - D24 - F21 - F19

1. Introduction

Productivity is widely accepted as one of the key determinants of growth performance. It improves production capacity, which could boost economic growth of a country. Technology is said to be one of the main determinants of productivity and its changes have a permanent long-term effect on economic growth (Easterly and Levine, 2001). A substantial number of studies show that the major source of technological change leading to productivity growth comes from the research and development (R&D). R&D is defined as a project to resolve scientific or technological uncertainty in order to achieve an advance in science and technology. In

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general, R&D plays an important role in the innovation process which is vital for current and future production. Together with the innovation process, R&D speeds up the advancement of technology and assists in the creation of new products and the improvement of existing products.

In general, technological changes that contribute to productivity growth can come from both domestic and international R&D investment. There are two channels of technology transmission for international spillovers. The first channel is trade (Eaton and Kortum, 2002) where technological knowledge is transmitted through imports. The second channel of technology transmission is foreign direct investment (FDI), where the inflow of FDI is assumed to be accompanied by potential external effect on domestic-owned firms and foreign-owned firms. Although both domestic & international R&D investments encourage productivity growth, many FDI host countries benefit hugely from the later (Keller, 2004). Interaction with the R&D leader countries may also help the less developed countries to increase their productivity.

The aim of this study is to examine the most important source of R&D spillovers for productivity growth of South Korea. Three sources considered in the analysis are the domestic R&D investment, the imports and FDI. For the international spillovers, this study estimates the impact of R&D spillovers from the G-5 countries on South Korean productivity growth during the period of 1985 to 2005.[1] The choice of South Korea is based on the fact that it is one of the most innovative countries with huge investment in R&D activities. According to the OECD Science, Technology and Industry Scoreboard 2013, South Korea was placed second after Israel with R&D spending of 4.03 percent (over GDP). The importance of R&D as an important ingredient for growth has long been recognized. Recently, the South Korean government launched its Science and Technology (S&T) Basic Plan for 2008-2012 with the objective to increase domestic investment in R&D, which in return, will improve the country's productivity. South Korea spent more of its gross domestic expenditure on R&D and entrust KRW66.5 trillion over a five-year period since 2008, which is higher than KRW26 trillion spent by the previous budget. In order to stimulate private spending on R&D, the government also introduced an R&D investment tax incentive by increasing the tax deduction rate from seven percent to 10 percent on investment for R&D facilities. The measures taken by South Korea indicate that the country is highly focused on promoting domestic expenditure of R&D towards enhancing its technology and boosting the economic growth.

This study differs from previous similar studies as it focuses on the aggregate level of the economy. Previous studies such as Kim and Park (2003), Kwon (2005) and Singh (2004) focused on the link between R&D spillovers and productivity at the firm level. The studies highlighted the importance of foreign capital stock towards improving productivity growth in South Korean manufacturing firms. Kim and Park (2003) and Singh (2004) examined the relationship between R&D spillovers and productivity for 28 South Korean manufacturing sectors by using level-industry data and panel data, respectively. Meanwhile, Kwon (2005) investigated the R&D spillovers from Japan in South Korean manufacturing industries.

The following Section 2 provides a review of the literature. Section 3 highlights the study's model specification, econometric estimation methodology and description of variables. Section 4 discusses the empirical findings and Section 5 concludes.

[1] The G5 countries are France, Germany, United States, United Kingdom and Japan.

2. Literature review

Domestic and foreign transmission channels of technology are recognized as a fundamental factor of long-run growth (Singh, 2004). Previous studies that examined the importance of each channel on the productivity have shown mixed results. Most studies discovered a positive relationship between R&D capital stock and total factor productivity. For instance, Coe and Helpman (1995), Coe et al. (1995), Singh (2004) and Kim and Lee (2006) concluded that increasing investment in R&D may enhance productivity growth. Coe and Helpman (1995) studied 21 OECD countries including Israel during 1971 to 1991, Coe et al. (1995) examined 77 developing countries during 1971 to 1990, while Singh (2004) and Kim and Lee (2006) investigated productivity growth in 28 manufacturing industries in South Korea during 1970 to 2000 and 14 OECD countries during 1982 to 1993, respectively.

Several other studies such as Savvides and Zachariadis (2005), Kim and Park (2003; 2006), Kwon (2005) and Lee (2005), found that both domestic and foreign R&Ds are important determinants on productivity growth. However, these studies discovered that the foreign R&D has a greater impact on domestic productivity. The impact of the foreign R&D on domestic productivity could be seen especially in sectors with large share of imports or intra-industry trade(Kim and Park, 2003; 2006). For example, an increase of productivity growth in South Korean manufacturing industries during the period 1985 to 1996 is mainly due to the R&D spillovers from the Japanese industries.

Pottelsberghe and Lichtenberg (2001) and Kuo and Yang (2008) concluded that R&D spillovers as the most important channel to transmit technology or knowledge across countries. These studies identified trade and FDI as two significant channels in the R&D spillovers. In the context of trade, Keller (2004), Lee (2005), Singh (2004), Kim et al. (2009) and Azman-Saini (2009) identified that the imports embodied in foreign R&D capital stock are more important than FDI in distributing technology across countries. However, few empirical studies such as Braconier and Sjoholm (1998), Luh and Shih (2006) and Bitzer and Kerekes (2008), proved that FDI is more important than the imports in transmitting the positive impact of foreign R&D.

3. Methodology and data

3.1 Model Specification

This study adopts a basic model formed by Coe and Helpman (1995), which was adapted by Lichtenberg and Pottelsberghe (1998) and Pottelsberghe and Lichtenberg (2001). The basic formation of the model is:

$$TFP_t = \beta_0 + \beta_1 S_t^d + \beta_2 S_t^{ff} + \varepsilon_t \qquad (1)$$

where *TFP* is total factor productivity, S^d is domestic R&D capital stock, S^f is foreign R&D capital stock and ε is an error term.

Following Pottelberghe and Lichtenberg (2001),the import-weighted R&D capital stock, S^{fm} is computed as follows:

$$S^{fm} = \sum_{j \neq i} \frac{m_j s_j^d}{y_j} \tag{2}$$

where j is an index for the G-5 countries namely France, Germany, Japan, United Kingdom and United States, m_j indicates the flow of imports of goods and services by South Korea from country j, S_j^d refers to the gross domestic expenditure on R&D for country j and y_j is the GDP for country j.

The inward FDI-weighted foreign R&D capital stock, S^{ff} is computed as follows:

$$S^{ff} = \sum \frac{f_j}{k_j} S_j^d \tag{3}$$

where f_j indicates the flow of FDI from country j into South Korea, and k_j refers to the gross fixed capital formation of country j, both are expressed in constant dollars.

3.2 Estimation Procedure

The empirical analysis involves several stages. The first stage determines the stationarity properties of the variables (*TFP, S^d, S^{fm} and S^{ff}*). The second stage utilizes the *F-test* to analyze the long-run cointegration relationship between the variables. The third stage estimates the elasticity of the long-run relationships. Finally, the fourth stage determines the short-run elasticity.

Unit Root Tests

Two widely used methods of unit root tests; Augmented Dickey Fuller (ADF) test is employed to test the stationarity of variables. The unit root tests are performed at level and first difference. The reason focusing two methods of unit root tests is to increase the confidence in the results with supporting evidence.

Autoregressive Distributed Lag (ARDL) Bounds Test Approach to Cointegration

The Autoregressive Distributed Lag (ARDL) bound test approach by Pesaran et al. (2001) is adopted to determine the existence of long-run relationships and the estimation of the long-run and short-run coefficients. In general, the ARDL bounds test approach is based on the Ordinary Least Squares (OLS) estimation of a conditional Error Correction (EC) model for cointegration analysis. In this study, the method is used to determine the existence of long-run relationships and to estimate the long-run and short-run coefficients of the R&D spillovers. This method is selected based on its ability to efficiently estimate the cointegration in small sample cases. Moreover, it can be applied irrespective whether the regressors are I(1) or I(0) or mutually cointegrated (Pesaran et al., 2001).

For this study, the ARDL model for the relationship between South Korean TFP and R&D capital stock is written as follows:

$$\begin{aligned} \Delta LTFP_t &= \alpha_0 + \beta_1 LTFP_{t-1} + \beta_2 LS_{t-1}^d + \beta_3 LS_{t-1}^{fm} + \beta_4 LS_{t-1}^{ff} \\ &+ \sum_{i=1}^{p} \delta_i \Delta LTFP_{t-i} + \sum_{i=0}^{q} \theta_i \Delta LS_{t-i}^d + \sum_{i=0}^{r} \varphi_i \Delta LS_{t-i}^{fm} + \sum_{i=0}^{s} \gamma_i \Delta LS_{t-i}^{ff} + \varepsilon_t \end{aligned} \tag{4}$$

where *LTFP* is total factor productivity, LS^{d} is domestic R&D stock, LS^{fm} is foreign R&D stock embodied in imports and LS^{ff} is the foreign R&D stock embodied in FDI. All variables are in natural logarithm forms. The *p, q, r, s* are the optimal lag lengths for each variable while Δ is the first difference operator.

The F-test is used to test the existence of long-run relationship among the variables in the equation. A joint significance test is performed in order to test the null hypothesis of no cointegration by setting the coefficients of all one lagged level variables to be equal to zero against the alternative hypothesis that the coefficients of all one lagged level variables are not equal to zero. The calculated F-statistics are compared to the respective critical values for small sample size cases, as tabulated by Narayan (2004, 2005)[2]. These critical values contain upper and lower bands covering all possible classification of the variables into I(1), I(0) and mutually cointegrated. If the F-test statistic is greater than the upper bound, then the null hypothesis of no cointegration is rejected, which implies that the variables in the model are cointegrated. If the test statistic is smaller than the lower bound, then the null hypothesis of no cointegration cannot be rejected, which suggests that the variables are not cointegrated. However, if the F-test statistic lies between the bounds, the conclusion can only be made through the order of integration of the variables. In this situation, the variables are suggested to be cointegrated if the variables are I(0) on the basis of lower bound and not cointergated if the variables are I(1) on the basis of upper bound.

Once cointegration is established, the conditional ARDL *(p,q,r, s)* long-run model for LTFP can be estimated using the following model:

$$\Delta LTFP_t = \alpha_1 + \sum_{i=1}^{p} \delta_i \Delta LTFP_{t-i} + \sum_{i=0}^{q} \theta_i \Delta LS^{d}_{t-i} + \sum_{i=0}^{r} \varphi_i \Delta LS^{fm}_{t-i} + \sum_{i=0}^{s} \gamma_i \Delta LS^{ff}_{t-i} + \varepsilon_t \tag{5}$$

The order of lags in the ARDL model is selected using the Schwarz Bayesian Criterion (SBC). In the final stage, this study estimates the short-run dynamic parameters using an error correction model associated with the long-run estimates. This is specified as follows:

$$\Delta LTFP_t = \alpha_1 + \sum_{i=1}^{p} \delta_{2i} \Delta LTFP_{t-1} + \sum_{i=0}^{q} \theta_{2i} \Delta LS^{d}_{t-i} + \sum_{i=0}^{r} \varphi_{2i} \Delta LS^{fm}_{t-i} + \sum_{i=0}^{s} \gamma_{2i} \Delta LS^{ff}_{t-i} + \psi ECT_{t-1} + \vartheta_t \tag{6}$$

where all coefficients for the short-run equation are short-run dynamic coefficients of the model's convergence, ψ represents the speed of adjustment and ECT_{t-1} is the error correction term.

2 The critical values provided by Pesaran et al. (2001) are calculated on the basis of large sample size of 500 and 1000 observations and 2000 and 4000 replications respectively.

3.3 Data

This study examines the R&D spillovers from theG-5 countries (France, Germany, Japan, United Kingdom and United States) into South Korea for the period 1985-2005. Data for the G-5 countries are obtained from the OECD Main Science and Technology Indicators while data for South Korea are taken from the World Development Indicators (WDI) and the OECD Statistics. Bilateral data on imports and FDI inflows are taken from the OECD statistics and the IMF Direction of Trade databases, respectively.

The TFP series for South Korea are computed using the following formula:

$$TFP = Y / K^{\beta} L^{1-\beta} \tag{7}$$

where Y represents total production, TFP refers to the total factor productivity while K and L denote stock of physical capital and total labor force, respectively. β is the share of capital income in GDP, which is set to 0.4, following Chenery et al. (1986).

The benchmark for R&D capital stock is calculated using the following formula:

$$S_0 = R_0 / (g - \delta) \tag{8}$$

where S_0 is the benchmark for R&D capital stock, R_0 is the R&D expenditure at the beginning of the sample period, g is the average growth rate of R&D expenditure which and δ is the depreciation rate.

The R&D capital stock is computed by using the perpetual inventory method as follows:

$$S_t = (1-\delta) S_{t-1} + R_t \tag{14}$$

where δ is the depreciation rate, which is assumed to be five percent (Coe and Helpman, 1995; Keller, 2002) and R denotes the R&D expenditure.

4. RESULTS AND DISCUSSION

4.1 Unit Root & Bounds Tests

Results of the Augmented Dickey-Fuller (ADF) unit root test in Table 1 indicate that all the variables are either stationary at level, I(0); or at first difference, I(1). Therefore, the bound test which requires the independent variables to be I(0) or I(1), can be adopted in estimating the relationship of the variables.

Table 1 The Augmented Dickey-Fuller (ADF) Test

Variable	Level	First Difference
TFP	-2.430 (0.356)	-4.415 (0.012)**
S^d	-0.582 (0.968)	-3.680 (0.049)**
S^{fm}	-3.129 (0.127)	-4.414 (0.012)**
S^{ff}	-2.601 (0.108)	-2.890 (0.064)*

*** and * denote significance levels at, 5% and 10% respectively.*
The figures in parentheses is the p-value..

Prior to the bounds test, the maximum lag length of the model is determined using the Schwarz Bayesian Criterion (*SBC*) and the results suggest that the maximum lag length of the model is 1. Subsequently, the Wald test is performed to determine the long-run cointegration among the variables. The F-test statistic obtained from this test is compared with Table III (unrestricted intercept; no trends) in Narayan (2005). The results, as shown in Table 3, indicate that the value is above the upper bound critical value which implies that the South Korean TFP is cointegrated with the independent variables of domestic R&D (S^d), foreign R&D stock embodied in imports (S^{fm}), and inward FDI (S^{ff}). This result suggests that there is a long run cointegration relationship among the variables.

Table 2 Wald F-statistics

Model		**F-statistic**
Model: $TFP = f\,[(S^d), (S^{fm}), (S^{ff})]$		9.536**
Narayan (2005)	k=3	n=30
Critical Values	**Lower Bound**	**Upper Bound**
1%	5.333	7.063
5%	3.710	5.018
10%	3.008	4.150

** and * denote significance levels at, 5% and 10% respectively.
Critical values are cited from Narayan (2005) (Table case III: Unrestricted intercept and no trend).

4.2 Autoregressive Distributed Lag (ARDL) Approach

4.2.1 Long-run Relationship

The ARDL technique is used to estimate both of the short-run and long-run coefficients of the variables. The estimation of the long-run relationships requires the determination of optimum lag lengths which maximum is capped at two due to the small sample size. According to Pesaran et al. (2001), the best technique to determine the optimum lag lengths is by using the SBC as its results are more precise than other techniques. Results of the SBC show that the optimum lag lengths for *Equation (10)* are (*1, 2, 1, 1*) as values for (p, q, r, s) to construct the ARDL Bounds test. Using the result of the optimum lag lengths, the long-run elasticity for each variable is computed using the Wald test. According to Pesaran et al. (2001), the long run elasticity can be determined using the following formula:

$$\frac{\sum \beta_{i,t}}{1-\sum \beta_{j,t}} \tag{13}$$

where β_i denotes the coefficients for each independent variable and the constant term while β_j refers to the coefficients of the dependent variable.

Table 3 Estimation of Long-run Coefficients

Variable	Coefficient	Standard Error	t-statistics	p-values
S^d	0.218488	0.083397	2.619850	0.0256**
S^{fm}	-0.049057	0.024332	-2.016132	0.0714*
S^{ff}	0.061356	0.027482	2.232558	0.0496**
Constant	2.158381	0.641313	3.365565	0.0072**

** and * denote significance levels 5% and 10% respectively.

Table 4 shows the results of long-run coefficients for the domestic R&D and the foreign R&D (the imports and the inward FDI). The positive significant result for S^d suggests that the domestic R&D is an important determinant of the South Korean productivity growth. Meanwhile, the negative significant result for the import-weighted foreign R&D capital stock suggests that there is an inverse relationship between the imports and the domestic productivity in the long run. These results are consistent with Kim and Kim (1997) and Coe et al. (1995). For the foreign R&D capital stock embodied in inward FDI (S^{ff}), the result shows that the variable is positive and significant which indicates that the inflow of FDI is beneficial to the South Korean long-run productivity.

The coefficient for S^d has a higher value than the coefficient for S^{ff}, suggesting that the domestic R&D has a greater impact on the country's productivity compared to foreign R&D embodied in the inward FDI. A study by Coe and Helpman (1995) showed that the impact of the domestic R&D on productivity is greater in high-income OECD countries compared to low-income countries. However, among the foreign R&D spillovers, the inward FDI are found to be a more important channel compared to the imports, in improving the domestic productivity in the long run. Our finding is consistent with Braconier and Sjoholm (1998) who estimated that the inward FDI is an effective channel to transmit technology across countries.

4.2.2 Short-run Relationship

The Error Correction Model (*ECM*) is adopted to estimate the short-run determinant of South Korean productivity. Table 8 shows the regression results of the short-run relationships using *ARDL* model. The negative coefficient value for *ECT(-1)* indicates that the variable converge in the long run and the convergence to equilibrium of South Korean TFP in one year is corrected by approximately 31.65 per cent in the following year. Meanwhile, the p-value of *ECT(-1)* shows that there is evidence of short-run cointegration relationships among variables. The results show that the domestic R&D and the imports have a positive and significant impact on the growth of domestic productivity in the short run. This indicates that an increase in both activities may boost the productivity in South Korea. Interestingly, the results also show that the improvement in the FDI inflow may reduce domestic productivity in the short run.

Table 4 Error Correction Representation of ARDL Model (Short-run Coefficients)

Variables	Coefficients	Standard Error	t-statistic	p-values
S^d	0.141	0.030	4.676	0.000**
S^{fm}	0.018	0.010	1.871	0.082*
S^{ff}	-0.038	0.007	-5.321	0.000**
ECT (-1)	-0.316	0.034	-9.262	0.000**
Constant	0.681	0.072	9.436	0.000

** and * denote significance levels 5% and 10% respectively.

4.3 Discussion

In general, the overall empirical result shows that both domestic and foreign R&D have a positive impact on South Korean domestic productivity growth in the short run and in the long run. Nonetheless, the result suggests that the impact of the domestic R&D on productivity is greater than the impact of the foreign R&D. This finding is consistent with Azman-Saini (2009) who mentioned that South Korean relies more on the domestic R&D to enhance productivity by upgrading domestic technology. In fact, most previous studies found that developed countries get larger benefit from their domestic R&D while developing countries gain greater positive impact from foreign R&D (Coe et al., 1995)

The result also reveals that South Korean TFP enjoys the positive impact of the foreign R&D spillovers from the G-5 countries. However, the significant channel of spillovers differs between the short run and the long run. In the short run, the imports of goods and services have been identified as the major spillover channel to transmit technology across border. This result is consistent with Keller (2004), Lee (2005), Singh (2004) and Azman-Saini (2009). According to Kim et al. (2009), imports from the G-5 countries are more likely to embody advanced technology spillovers compared to imports from other countries.

In the long run, the result suggests that the inward FDI is more important in transmitting knowledge or technology across countries. The imports are no longer an important channel for technology diffusion. One possible explanation is that the increasing imports of goods and services encourage domestic import-substituting firms to become more competitive by adopting more efficient production techniques and engage in innovation to compete with foreign firms. Eventually, the imports can no longer enhance productive efficiency in the long run. This result is consistent with Braconier and Sjoholm (1998), Luh and Shih (2006) and Bitzer and Kerekes (2008). The inward FDI received by South Korea from the G-5 countries induces significant technological transfer, which often leaks out to domestic firms. Thus, South Korea can exploit and take advantage of potential technology diffusion to upgrade its own technological innovations and the R&D spillovers will increase its domestic productivity.

5. Conclusion

The importance of technology as a determinant of the level of productivity has been well acknowledged in the literature. The improvement in technology can be influenced by several factors including the R&D expenditure. Meanwhile, investment in R&D can come from both domestic and foreign sources. Realizing the importance of R&D spillovers, this study examines several important channels of R&D in the productivity growth of South Korea, a country which experiences a massive growth in technology and productivity. Our estimation results suggest that the domestic R&D has a greater impact on South Korean productivity growth, both in the short run and the long run. The results also suggest that the foreign R&D spillovers are also important to South Korean productivity growth. However, in the short run, only the imports of goods and services are significant to the changes in productivity growth while the inward FDI plays a bigger role in the long run.

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