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ABSTRACT

North-South Technology Spillovers: The Relative Impact of Openness and Foreign R&D*

This paper examines the relative contribution of openness and the R&D content of trade to TFP growth for North-South trade-related technology diffusion. The measure of foreign R&D used in the literature on trade-related technology diffusion imposes identical contributions of openness and the R&D content of trade to TFP. We allow these contributions to differ and show that openness has a greater impact on TFP growth than R&D. These results imply that the impact of openness on TFP in developing countries is larger than previously obtained in this literature. In other words, developing countries can obtain larger productivity gains from trade liberalization than previously thought.

JEL Classification: F10, F15, O19, O24, O33

Keywords: technology diffusion, R&D, openness, North-South

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NORTH-SOUTH TECHNOLOGY SPILLOVERS: THE RELATIVE IMPACT OF OPENNESS AND FOREIGN R&D

1. Introduction

The theory of endogenous growth based on increasing returns to knowledge accumulation originated with Romer (1986, 1990). One of the implications of this theory is that policies affecting knowledge accumulation can have a permanent effect on the rate of economic growth.

Knowledge is assumed to differ in two ways from traditional inputs. First, it has public good characteristics; and second, new knowledge is complementary to existing knowledge so that the marginal product of additional units of knowledge increases. For instance, a new idea that is generally available raises productivity and increases market size, and this raises the return to additional ideas. And a high-knowledge economy is likely to be able to make productive use of an advanced piece of knowledge, while a knowledge-scarce economy might not.

The assumption that knowledge is a public good means that, once generated, it diffuses costlessly and is available to the entire economy. Though knowledge clearly possesses public goods characteristics, most knowledge is privately produced and is rarely a *pure* public good whose diffusion is instantaneous or free. Much new knowledge is embedded in new products, in improved qualities of existing products and in new processes. This is especially true for international knowledge diffusion where additional barriers exist, including tariffs and quantitative restrictions on imports, different standards and regulations, and higher communication costs (including those related to language differences).

In the case of domestic knowledge diffusion, Griliches (1957) showed for the US that the adoption of hybrid corn was gradual, with logistic or S-shaped cumulative adoption process. His work spawned other studies that found the same technology diffusion patterns, implying that it might take a long time until most firms adopt the new technology.[1] It follows that knowledge accumulation can occur through increased diffusion of existing knowledge, production of new knowledge, or both.

This paper is concerned with the process of international technology diffusion where trade-related knowledge diffusion can occur through an increase in exposure to that knowledge through the channel of trade, through an increase in the knowledge-content of that trade, or both. This paper investigates how these two components of knowledge diffusion affect productivity. Given the higher cost of international relative to domestic knowledge diffusion, examining the differential impact of these two components of knowledge diffusion in an international context seems particularly promising.

A recent literature has examined the impact of trade on knowledge diffusion by constructing measures of access to foreign knowledge and estimating the latter's effect on productivity.[2] The seminal paper is Coe and Helpman (1995). It estimates the impact on total factor productivity (TFP) of "foreign R&D", where foreign R&D is defined as the sum of trading partners' R&D stocks (the knowledge-content of trade), weighted by the

[1] For instance, Greenwood (1997) found that it took 54 years for adoption to rise from 10% to 90% of existing firms for steam locomotives and 25 years for diesels in the US, and Manuelli and Seshadri (2003) found it took 35 years for tractors. Gradual adoption is typically attributed to some market imperfection, including lobbying (Parente and Prescott, 1994), imperfect information (Jovanovic and MacDonald, 1994) or learning by doing (Jovanovic and Lach, 1989; Jovanovic and Nyarko, 1996). Manuelli and Seshadri (2003) obtain the same diffusion pattern for tractors in a frictionless model, with gradual adoption due to the change in exogenous variables over time, including labor costs.

[2] Recent interest in the relationship between trade and growth and in international technology spillovers is based on the development of endogenous growth theories (e.g., Romer, 1986, 1990) and their application to the open economy case (Grossman and Helpman, 1991).

bilateral trade shares (a measure of knowledge quantity). Using aggregate data, Coe and Helpman (1995) and Lumenga-Neso et al. (2001) find for developed countries and Coe et al. (1997) for developing countries that foreign R&D has a significantly positive impact on TFP, with Schiff et al. (2002) obtaining similar results for industry-level analysis for developing countries.

These papers treat the two components of trade-related knowledge diffusion—i.e., openness and trading partners' R&D stocks—symmetrically in their empirical analysis. This paper subjects the symmetry assumption to rigorous testing and concludes that the impact of the two components is asymmetric. We show that openness plays a more important role than R&D stocks in North-South knowledge diffusion and has a greater impact on productivity than found in the existing literature.

The paper is organized as follows. Section 2 sets forth a brief analytical framework. Section 3 presents the empirical implementation, Section 4 provides the empirical results, and Section 5 compares them with those in the literature. Section 6 concludes.

2. Analytical Framework

This paper investigates the relative contributions to a developing country's TFP of the R&D performed in OECD countries and of the degree of access to this knowledge through trade. Total factor productivity TFP is assumed to be given by:

$$TFP = TFP(T, Z), \tag{1}$$

where T denotes technological knowledge, and Z is a vector of other factors affecting TFP including, for instance, education. Technological knowledge T in a given country is assumed to be given by

$$T = T(RD, NRD); \; T_1, T_2 > 0, \tag{2}$$

where *RD* is the stock of R&D produced in that country, *NRD* is the access to the trading partners' R&D stocks – referred to in the literature as "foreign R&D," and T_1 and T_2 are the first order derivatives with respect to *RD* and *NRD*, respectively. Access to the foreign stock of R&D, *NRD*, is assumed to be given by

$$NRD = NRD(OPEN, RDC); NRD_1, NRD_2 > 0, NRD_{11} < 0. \tag{3}$$

Thus, *NRD*, the level of access to trading partners' R&D stocks, is a function of *OPEN*, the degree of a country's openness, and *RDC*, a measure of trading partners' R&D stocks (i.e., a measure of the R&D content of the country's trade).[3] The second derivative NRD_{11} is assumed to be negative to reflect the fact that the additional knowledge a country obtains from the imports of a given machine is likely to diminish with the number of units of that machine that it imports.

Past studies that have examined trade-related technology diffusion have assumed that openness and trading partners' R&D stocks enter symmetrically in *NRD*, i.e., that equation (3) takes the form:

$$NRD = NRD(OPEN * RDC). \tag{4}$$

and that equation (1) takes the form:

$$TFP = TFP(T(RD, OPEN * RDC), Z). \tag{5}$$

[3] *NRD* is what is referred in the literature as "foreign R&D".

This paper investigates whether the variables *OPEN* and *RDC* actually enter symmetrically in the TFP equation. We test this hypothesis for North-South trade, i.e., between OECD and developing countries.

3. Empirical Implementation

We make use of a data set of industry-level trade-related technology diffusion used in Schiff et al. (2002). The data set consists of 16 manufacturing industries, 24 developing countries, 15 OECD trading partners, and 22 years (from 1977 to 1998). The 16 industries are further divided into high and low R&D-intensity groups (with R&D intensity defined as the ratio of expenditures on R&D to value added). The average R&D intensity is 1.3% for the "low" group and 11% for the "high" group. High R&D intensity industries are shown in italics in footnote 4, a further discussion of R&D intensities in footnote 5, and a list of developing (OECD) countries in footnote 6 (7).[4] [5] [6] [7] As in Coe et al. (1997), domestic R&D is not included due to the lack of data.

Schiff et al. (2002) define the knowledge obtained through trade in industry i of developing country c, NRD_{ci}, as:

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[4] The 16 manufacturing industries are: 31-Food, Beverage & Tobacco; 32-Textiles, Apparel & Leather; 33-Wood Products & Furniture; 34-Paper, Paper Products & Printing; *351/2-Chemicals, Drugs & Medicines; 353/4-Petroleum Refineries & Products*; 355/6-Rubber & Plastic Products; 36-Non-Metallic Mineral Products; 371-Iron & Steel; 372-Non-Ferrous Metals; 381-Metal Products; *382-Non-Electrical Machinery, Office & Computing Machinery; 383-Electrical Machinery and Communication Equipment; 384-Transportation Equipment; and 385-Professional Goods*; and 39-Other Manufacturing.

[5] For the "high" group, the average R&D intensity *minus* two standard deviations is 3.8%, which is larger than the average *plus* two standard deviations of the "low" group or 3.1%. Assuming a normal distribution, the hypothesis that any of the industries in the "high" R&D intensity cluster belongs to the "low" cluster is rejected at the 1% significance level.

[6] The 25 developing countries are: Bangladesh, Bolivia, Chile, Cameroon, Colombia, Cyprus, Ecuador, Egypt Arab Rep., Guatemala, Hong Kong- China, Indonesia, India, Iran Islamic Rep., Jordan, Korea Rep., Kuwait, Mexico, Malawi, Malaysia, Pakistan, Philippines, Poland, Trinidad and Tobago, Venezuela.

[7] The 15 OECD countries are: Australia, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, Spain, Sweden, United Kingdom, and United States.

$$NRD_{ci} \equiv \sum_j a_{cij} RD_{cj} = \sum_j a_{cij} \left[\sum_k \left(\frac{M_{cjk}}{VA_{cj}} \right) RD_{jk} \right], \qquad (11)$$

where c (k) indexes developing (OECD) countries, j indexes industries, M (VA) (RD) denotes imports (value added) (R&D), and a_{cij} is the input-output coefficient, which measures for country c the share of industry-j imports that is sold to industry i.

The first part of equation (11) says that, in developing country c, *NRD* in industry i (in country c), NRD_{ci}, is the sum, over all industries j, of RD_{cj}, the industry-j foreign R&D obtained through imports, multiplied by a_{cij}, the share of industry-j imports that is sold to industry i. The second part of equation (11) says that RD_{cj} is the sum, over OECD countries k, of M_{cjk}/VA_{cj}, the imports of industry-j products from OECD country k per unit of industry-j value added (i.e., the bilateral openness share), multiplied by RD_{jk}, the stock of industry-j R&D in OECD country k.

We define an openness variable as:

$$OPEN_{ci} = \sum_j a_{cij} \left[\sum_k \left(\frac{M_{cjk}}{VA_{cj}} \right) \right] \qquad (12)$$

which is derived from equation (11) by setting $RD_{jk} = 1,\ \forall j,k$.

Second, we define an R&D variable

$$RDC_{ci} = \sum_j a_{cij} \left[\sum_k RD_{jk} \right] \qquad (13)$$

which is derived from equation (11) by setting $M_{cjk}/VA_{cj} = 1,\ \forall c, j, k$.

As in Coe et al. (1997), Schiff et al. (2002) and others, education is included in the regression as a control variable. Two alternative equations are estimated:

$$\log TFP_{cit} = \beta_0 + \beta_N \log NRD_{cit} + \beta_T \log OPEN_{cit} + \beta_E E_{ct}$$

$$+ \sum_t \beta_t D_t + \sum_c \beta_c D_c + \sum_i \beta_i D_i + \varepsilon_{cit}, \qquad (14)$$

and

$$\log TFP_{cit} = \beta_0^{'} + \beta_N^{'} \log NRD_{cit} + \beta_L^{'} \log RDC_{cit} + \beta_E^{'} E_{ct}$$

$$+ \sum_t \beta_t^{'} D_t + \sum_c \beta_c^{'} D_c + \sum_i \beta_i^{'} D_i + \varepsilon_{cit}^{'}, \qquad (15)$$

where E denotes education, and D_t (D_c) (D_i) represents time (country) (industry) dummies. The effects for high and low R&D intensity industries are estimated by introducing a dummy variable, DR, with DR = 1 for high R&D-intensity industries and DR = 0 otherwise.

4. Empirical Results

We need to consider the possibility that two or more variables might be trended and contain unit roots, making the regression results spurious (unless the variables are co-integrated). The unit root hypothesis was rejected at the 1% significance level for log *TFP*, log *NRD*, log *OPEN* and log *RDC*.[8]

The estimation results are presented in Tables 1 and 2. The education variable E is significant at the 1% level in all six regressions, with a one percentage point increase in education raising *TFP* by between 6.8 and 7.5 percent.

Regressions (i) and (ii) in Table 1 are reproduced from Schiff et al. (2002). They impose symmetric effects of openness and R&D on *TFP*. Regression (i) shows a positive impact of *NRD* on *TFP* (significant at the 1% level), with an elasticity of about .19.

[8] Test results are available from the authors upon request.

Regression (ii) distinguishes between low and high R&D-intensity industries, and shows an elasticity of about .14 for low R&D-intensity industries and of .28 for high R&D-intensity industries, both significant at the 1% level. As might be expected, foreign R&D has a greater impact on the productivity of R&D-intensive industries.

Columns (iii) and (iv) in Table 2 regress TFP on *NRD* and *OPEN* (see equation (14)). Regression (iii) shows that the elasticity of TFP with respect to R&D is –.012 and not significantly different from zero, and the elasticity with respect to openness is about .24 (.251 - .012), significant at the 1% level. Regression (iv) distinguishes between low and high R&D-intensity industries. For low R&D-intensity industries, the elasticity of TFP with respect to R&D is -.065 and not significantly different from zero, and the elasticity with respect to openness is .23 (.295 - .065), significant at the 1% level. For high R&D-intensity industries, the elasticity of TFP with respect to R&D is .22 (.285 - .065), significant at the 1% level, and the elasticity with respect to openness is about .27 (.22 +.295 - .244).

The results from regression (iv) imply that R&D has no impact on the TFP of low R&D-intensity industries and has a significant impact on the TFP of high R&D-intensity industries. Second, openness has a significant impact on the TFP of both low and high R&D-intensity industries. The impact of openness is larger than that of R&D, significantly so for low R&D-intensity industries and somewhat less so for high R&D-intensity industries. The results on the importance of R&D are quite plausible. One would expect the embodied technology or R&D content of imports to matter more in industries where technology plays a more important role, i.e., in R&D-intensive industries.[9]

Columns (v) and (vi) in Table 2 correspond to equation (15). Regression (v) shows an elasticity of TFP with respect to openness equal to about .37 (significantly different from zero at the 1% level) and with respect to R&D not significantly different from zero (-.039). These results confirm those of regression (iii).

Regression (vi) shows an elasticity of TFP with respect to openness equal to about .29 for low R&D-intensity industries and of .45 for high R&D-intensity industries, both significant at the 1% level. The elasticity of TFP with respect to R&D is not significantly different from zero for low R&D-intensity industries (.046 = .294 - .248) or for high R&D-intensity industries (.013 = .046 + .156 - .189). These results confirm those of regression (iv), though the elasticities with respect to openness in both industry groups are larger in this case and the elasticity with respect to R&D in high R&D-intensity industries is smaller.

5. Comparison with the literature

The results obtained here imply that the impact of openness on TFP in developing countries is greater than that shown in columns (i) and (ii) where the effects of openness and R&D are constrained to be symmetric. For all industries taken together, the elasticity of TFP with respect to openness is .19 in the case of symmetry and is between .24 and .37 in the absence of symmetry. When industries are split between high and low R&D-intensity industries, the elasticity of TFP with respect to openness is .14 for low R&D-

[9] For low R&D-intensity industries, only openness matters. This result could at least partly reflect the fact that greater openness has a disciplining effect by increasing the level of contestability and competitiveness of the domestic industry.

intensity industries in the case of symmetry, and between .23 and .29 in the unconstrained case. For high R&D-intensity industries, the elasticity is .28 under symmetry, and is between .27 and .45 in the unconstrained case. Thus, the openness elasticity for the low R&D-intensity industries is between 60 and 100 percent larger than when symmetry between the R&D and openness effects is imposed, and between 0 and 60 percent larger for the high R&D-intensity industries.

Coe et al. (1997) estimated the impact of North-South R&D spillovers at the aggregate level and tried a variety of specifications. In their preferred specification, the elasticity of TFP with respect to NRD is .058 and the elasticity of TFP with respect to the share of imports to GDP (openness) is .279, both significant at the 1% level.[10]

Falvey et al. (2002) estimate North-South R&D spillovers at the aggregate level and use various definitions of NRD. They conclude that the specifications that include the level of imports result in positive coefficients for the effect of knowledge spillovers while the others do not.

6. Conclusion

A recent literature has examined the impact of trade-related technology diffusion on productivity (TFP). That literature imposed symmetry between the impact of openness and that of the R&D content of trade. This paper examines this issue in the context of North-South technology diffusion and shows that the assumption of symmetry is not warranted in either case. The main findings are as follows:

i) openness has a greater impact on TFP than the R&D content of trade;

[10] Coe et al. (1997) use imports of machinery and equipment rather than total imports.

ii) the impact of openness on TFP is greater than is obtained when symmetry is imposed; and

iii) the impact of the R&D content of trade on TFP is not significantly different from zero in low R&D-intensity industries and may be positive in R&D-intensive industries.

These results suggest that the gains from trade liberalization in developing countries are likely to be larger than under the symmetry assumption, as was previously obtained in the literature.

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Table 1. Determinants of TFP in Developing Countries: Identical Impact of Openness and R&D

Variables	(i)	(ii)
log NRD	**0.188** ***(6.11)****	**0.138** ***(4.03)****
log NRD*DR		**0.141** ***(3.52)****
E	**6.831** ***(4.34)****	**6.823** ***(4.34)****
Adjusted R^2	**0.23**	**0.24**
No. of Observations	**5721**	**5721**

Note: Figures in parentheses are t-statistics. A significance level of 1% is indicated by ***. Regression results on country, year and industry dummies, and the constant, are not reported. NRD is the trade-related North-foreign R&D defined in equation (11), E is the secondary school completion ratio for the population aged 25 and above, and DR = 1 for R&D-intensive industries and DR = 0 for low R&D-intensity industries.

Table 2. Determinants of TFP in Developing Countries: Separating the Impact of Openness and R&D

Variables	(iii)	(iv)	(v)	(vi)
logNRD	**-0.012** ***(-0.19)***	**-0.065** ***(-0.99)***	**0.369** ***(8.82)******	**0.294** ***(6.31)******
logNRD*DR		**0.285** ***(4.02)******		**0.156** ***(3.5)******
logOPEN	**.251** ***(3.89)******	**0.295** ***(4.23)******		
log OPEN*DR		**-0.244** ***(-3.13)******		
logRDC			**-0.408** ***(-6.38)******	**-0.248** ***(-3.89)******
logRDC*DR				**-0.189** ***(-2.15)*****
E	**6.900** ***(4.37)******	**6.866** ***(4.37)******	**7.462** ***(4.74)******	**7.411** ***(4.72)******
Adjusted R^2	**0.23**	**0.24**	**0.24**	**0.24**
No. of Observations	**5721**	**5721**	**5721**	**5721**

Note: Figures in parentheses are t-statistics. Significance levels of 1% and 5% are indicated by *** and **, respectively. Results on country, year and industry dummies, and the constant, are not reported. NRD, OPEN and RDC are defined in equations (11), equation (12) and (13), respectively. E is the secondary school completion ratio for the population aged 25 and above. DR = 1 for R&D-intensive industries and DR = 0 for low R&D-intensity industries.