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North-South Trade-Related Technology Diffusion

Virtuous Growth Cycles in Latin America

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Abstract

This paper examines the impact on total factor productivity in Latin America and the Caribbean (LAC) and in other developing countries of trade-related technology diffusion from the North) (denoted by NRD), education, and governance, research and development The NRD value for a developing country is an average of R&D stocks in the North, with weights related to openness with the North. Industry-specific NRD is based on the North's industry-specific R&D, North-South trade patterns, and input-output relations in the South. The main findings are: i) the impact of education and governance on TFP is significantly larger in LAC than in other developing countries, while the opposite holds for NRD; and ii) education, governance and NRD have additional effects on TFP in LAC's R&D-intensive industries through their interaction with either or both of the other two variables; and iii) since NRD increases with openness and with R&D in the North, both variables raise the South's TFP directly as well as through their interaction with education and governance. These interaction effects imply that increasing the level of any of the three policy variables—education, governance, or openness—results in virtuous growth cycles. These are smallest under an increase in one of these variables, stronger under an increase in two of them and strongest under an increase in all three variables.

This paper—a product of the Office of the Chief Economist, Latin America and Caribbean Region—is part of a larger effort in the department to understand the productivity impact of trade-related technology diffusion in the Region. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at mschiff@worldbank.org.

North-South Trade-Related Technology Diffusion: Virtuous Growth Cycles in Latin America*

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1. Introduction

This paper aims to examine the impact of international diffusion of technological knowledge in Latin America and the Caribbean (LAC) and total factor productivity (TFP). In principle, international diffusion can occur through various channels, including trade, FDI, licensing, attending conferences, access to scientific journals (say, through the internet), and other sources of cross-border communication. The main channels that have been studied are trade and FDI, and this paper focuses on the role of international trade. Second, we examine the importance, for productivity and for the impact of foreign R&D and openness on productivity, of policies regarding education and governance.

Education is likely to play an important role because of its impact on the capacity to absorb technological knowledge in general and innovations in particular. Governance is also likely to be important because problems of governance such as corruption, delays in obtaining required permits, and general administrative weakness would reduce the impact on TFP of the diffusion of technology and reduce the investments and training needed to adapt the new technologies to local conditions.

Grossman and Helpman (1991) explore endogenous growth theory in an open economy setting. They argue that a country's productivity rises with its trade volume. The basic idea is that goods embody technological know-how and therefore countries can acquire foreign knowledge through imports. Coe and Helpman (1995) provide an empirical implementation of the open economy endogenous growth model. They construct an index of foreign R&D as the trade-weighted sum of trading partners' stocks of R&D. They find for a sample of developed countries that both domestic and 'foreign' R&D have a significant impact on TFP, and that the latter increases with the general degree of openness of the economy and with openness towards the larger R&D producing countries.

Coe et al. (1997) examine the same issue for developing countries. They find that developing countries benefit more from foreign R&D spillovers, the more open they are and the more skilled is their labor force. These findings provide support for the hypothesis that trade is an important mechanism through which knowledge and technological progress is transmitted across countries.

This paper builds on Schiff et al. (2005). That paper expanded the work of Coe and Helpman (1995) and Coe et al. (1997) by examining these issues at the industry level. The idea is that importing countries learn from the knowledge embedded in the inputs that they import. As is shown in Section 2 below, our measure of the stock of foreign R&D obtained by an importing country at the industry level explicitly incorporates the production structure of the economy as reflected in the input-output relationships. This paper specifically examines the impact on TFP of trade-related international technology diffusion, education and governance for the LAC region.

The remainder of the paper is organized as follows. Section 2 sets forth the empirical implementation, Section 3 describes the data, and Section 4 presents the results. Section 5 concludes.

2. Empirical Implementation

Coe and Helpman (1995) estimate the impact on TFP of domestic and foreign R&D for OECD countries. Due to lack of domestic R&D, this paper focuses on estimating the impact on TFP of foreign R&D. This is unlikely to have a significant impact on our results because most of the world's R&D is performed in developed countries.[1]

We estimate TFP equations with pooled data, for a panel of 25 developing countries and 16 manufacturing industries. At the industry level, the stock of foreign R&D available in industry *i* of developing country *c*, NRD_{ci}, is defined as:

$$NRD_{ci} \equiv \sum_j a_{cij} RD_{cj} = \sum_j a_{cij} \left[\sum_k \left(\frac{M_{cjk}}{VA_{cj}} \right) RD_{jk} \right], \qquad (1)$$

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

The first part of equation (2) says that, in developing country *c*, foreign R&D in industry *i*, NRD_{ci}, is the sum, over all industries *j*, of RD_{cj}, industry *j*'s R&D obtained through imports from OECD countries, multiplied by a_{cij}, the share of imports of industry *j* that is sold to industry *i*. The second part of equation (2) 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 also examine the impact of education and governance. We would expect education and governance to have a positive effect on TFP. A higher quality of

[1] Coe et al. (1997) report that 96% of the world's R&D expenditures took place in industrial countries in 1990. Moreover, recent empirical work has shown that much of the technical change in OECD countries is based on the international diffusion of technology among OECD countries. For instance, Eaton and Kortum (1999) estimate that 87% of French growth is based on foreign R&D. Since developing countries invest much fewer resources in R&D than OECD countries, foreign R&D must be even more important for developing countries as a source of growth.

governance enables a more efficient allocation of resources and a higher TFP. And a higher level of education implies a more productive labor force and a higher level of TFP. The baseline estimated equation is:

$$lnTFP_{cit} = \beta_0 + \beta_N \ln NRD_{cit} + \beta_E E_{ct} + \beta_G G_c$$
$$+ \sum_t \beta_t D_t + \sum_c \beta_c D_c + \sum_i \beta_i D_i + \varepsilon_{cit}, \quad (2)$$

where E (G) denotes education (governance), and D_t (D_c) (D_i) represents time (country) (industry) dummies.

We further examine how the impact of *NRD* varies with industries' R&D intensity. We divide the industries into two groups according to their R&D intensity. The grouping of the industries in the two clusters—and their R&D intensity--is shown in Section 3. Equation (2) becomes:

$$lnTFP_{cit} = \beta_0 + (\beta_N + \gamma_N DR) \ln NRD_{cit} + \beta_E E_{ct} + \beta_G G_c$$
$$+ \sum_t \beta_t D_t + \sum_c \beta_c D_c + \sum_i \beta_i D_i + \varepsilon_{cit}; \quad (3)$$

where DR = 1 (0) for high (low) R&D-intensity industries. We also estimate equation (3) with DR replacing $\sum_i \beta_i D_i$.

These equations are estimated for 16 manufacturing industries in 9 LAC countries as part of the full sample of 25 developing countries. The parameters for LAC are estimated as differences from the parameters for the entire sample of developing countries in equations (2) and (3). Thus, equation (2) becomes:

$$lnTFP_{cit} = \beta_0 + (\beta_N + \alpha_N DLAC) \ln NRD_{cit} + \beta_E E_{ct} + \beta_G G_c$$
$$+ \sum_t \beta_t D_t + \sum_c \beta_c D_c + \sum_i \beta_i D_i + \varepsilon_{cit}; \quad (4)$$

We also estimate equation (4) with *DLAC* replacing $\sum_c \beta_c D_c$. Moreover, we estimate equation (4) with interaction of *DR* and *DLAC*, i.e.:

$$ln TFP_{cit} = \beta_0 + [\beta_N + \alpha_N DLAC + (\gamma_N + \delta_N DLAC)DR] ln NRD_{cit}$$

$$+ \beta_E E_{ct} + \beta_G G_c + \sum_t \beta_t D_t + \sum_c \beta_c D_c + \sum_i \beta_i D_i + \varepsilon_{cit}; \qquad (5)$$

We also estimate (5) with *DR* replacing $\sum_i \beta_i D_i$ and *DLAC* replacing $\sum_c \beta_c D_c$.

Finally, we examine the interaction between *NRD* and education, *NRD* and governance, education and governance, and between *NRD*, education and governance, in order to see whether any of these has a significant impact on TFP. This analysis is also conducted separately for LAC and non-LAC countries and for R&D-intensive and non-intensive industries.

3. Definition of Variables and Data Sources

Our sample consists of 16 manufacturing industries in the nine LAC countries being examined as well as in the other developing countries in our sample, over the period 1976-2005. The nine LAC countries are Bolivia, Chile, Colombia, Ecuador and Venezuela in South America; Guatemala, Mexico and Panama in the rest of Latin America; and Trinidad and Tobago in the Caribbean.[2] Argentina and Brazil were not included for lack of data.

[2] The other 16 developing countries are in East Asia (Hong Kong-China, Korea Rep.), South Asia (Bangladesh, India, Pakistan), South-East Asia (Indonesia, Malaysia, Philippines), Middle East (Egypt Arab Rep., Iran Islamic Rep., Jordan, Kuwait), Sub-Saharan Africa (Cameroon, Malawi), Mediterranean (Cyprus) and Europe (Poland).

The 16 industries consist of 6 R&D-intensive industries and 10 low R&D-intensity industries.[3] The R&D intensity of the 16 industries is based on US data. An industry's R&D intensity was calculated as R&D expenditures divided by the value added of that industry. They are grouped in low (10 industries) and high (6 industries) R&D intensity industries.[4]

The TFP index is calculated as the difference between value added and factor income, with inputs weighted by their income shares, i.e., $ln TFP = ln Y - \alpha\, ln L - (1-\alpha) ln K$, with α equal to the year-country-sector specific labor's share. Labor share equal to wages over value added. Value added, wages, and fixed capital formation are reported in current US dollars, and all are deflated using US GDP deflators (1990=100). The capital stocks are derived from the deflated fixed capital formation series using the perpetual inventory model with a 5% depreciation rate.

The R&D flow data are taken from the ANBERD 2000 (OECD) database (DSTI/EAS Division). The database covers 15 OECD countries from 1973 to 2002 at either the two-, three- or four-digit level.[5] R&D flows cover all intramural business enterprise expenditures, converted into US dollars, and then deflated using US GDP

[3] The 10 low R&D-intensity industries are: (1) 31-Food, Beverage & Tobacco; (2) 32-Textiles, Apparel & Leather; (3) 33-Wood Products & Furniture; (4) 34-Paper, Paper Products & Printing; (5) 355/6-Rubber & Plastic Products; (6) 36-Non-Metallic Mineral Products; (7) 371-Iron & Steel; (8) 372-Non-Ferrous Metals; (9) 381-Metal Products; and (10) 39-Other Manufacturing. The R&D-intensive industries are (1) 382-Non-Electrical Machinery, Office & Computing Machinery; (2) 383-Electrical Machinery and Communication Equipment; (3) 384-Transportation Equipment; (4) 385-Professional Goods; (5) 351/2-Chemicals, Drugs & Medicines; and (6) 353/4-Petroleum Refineries & Products.

[4] The R&D intensities for the 16 industries with ISIC codes 32, 33, 34, 31, 371, 381, 36, 355, 372, 39, ***351, 353, 382, 385, 383, and 384*** are, in percentage terms, 0.4, 0.6, 0.7, 0.8, 1.1, 1.3, 1.8, 2.2, 2.4, 2.8, ***7.9, 8.1, 8.1, 11.0, 11.6 and 18.5***, respectively (with the R&D-intensive industries and their R&D intensity in bold italics). The average R&D-intensity of the "high" cluster is 10.9% while that of the "low" cluster is 1.4% (with respective standard deviations of 3.6% and .9%), i.e., the "high" cluster is more than 8 times more R&D intensive than the "low" cluster. 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.

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

deflators (1990=100). Cumulative R&D stocks are derived from the deflated R&D flows using the perpetual inventory method with a 10% depreciation rate.

The country specific, time-invariant input-output matrices for the twenty-five developing countries are derived from GTAP. For each country-industry-year, the weights (bilateral openness shares—imports/value added) are derived from the World Bank database "Trade and Production" (Nicita and Olarreaga, 2001). Trade data were collected at the 4-digit level and input-output data at the 3-digit level for the period 1976-2005, and both were aggregated to 2- and 3-digit levels for consistency with the R&D data (16 industries).

The measure of education used is the share of the population aged twenty-five and above that completed secondary education. These data are obtained from the Barro and Lee (2005) dataset which provides five-year averages for 1960-2005.

As for governance, we use an average of six measures.[6] These were aggregated from a data base consisting of hundreds of variables, and range from – 2.5 to + 2.5 (Kaufmann, Kraay and Zoido-Lobaton, 1999, 2009). The range is smaller in our sample because it excludes industrial countries and a large number of developing countries.

4. Estimation Results

Table 1 presents overall estimation results as well as for LAC. Column (i) shows that the elasticity of TFP with respect to foreign R&D for low R&D-intensity industries is

[6] The first measure is "voice and accountability", a measure of the openness of the political process, civil liberties and political rights; the second one measures "political instability and violence"; the third one measures "government effectiveness," and includes the independence of the civil service from political pressures and the credibility of governments' policy commitment; the fourth one is the "regulatory burden," and includes the incidence of price controls and perceptions of burdens from excessive trade and business regulations; the fifth one is the "rule of law," including enforceability of contracts, crime incidence, and effectiveness of the judiciary; and the sixth is "graft" and measures perceptions of corruption.

positive, small and non-significant. The elasticity of TFP with respect to *NRD* for non-LAC developing countries is .248, while that for LAC is .027 (.248 - .221). Column (ii) shows that the elasticity for R&D-intensive industries in LAC (.130) is larger than for low R&D-intensity industries (.021) and the same holds for the non-LAC developing countries where the elasticity for R&D-intensive industries is equal to .345 > .264.

The education elasticity of TFP is greater for LAC than for other developing countries (Column (i)), with a value of 16.9 (= 4.6 + 12.3) for LAC and 4.6 for the other countries. Similar results obtain for governance, with the elasticity equal to about 3.2 in LAC and .7 for non-LAC countries.

Column (ii) shows similar results for education and governance. These results indicate that the TFP impact of North-South trade-related technology diffusion (the South's education and governance) is smaller (greater) in LAC than in non-LAC countries, with technology diffusion defined in equation (1). This suggests the possibility of greater interaction effects in LAC than in other developing countries, with the education and governance variables capturing some of the effects of foreign R&D. These potential interaction effects are examined in Table 2.

4.1. Interaction with Education

In column (i) in Table 2, education is interacted with foreign R&D in R&D-intensive industries for non-LAC (ln*NRD***DR***E*) and LAC countries (ln*NRD***DR***DLAC***E*). The interaction effect for non-LAC countries is negative (-.060) but not significant, while the interaction effect for LAC countries is .224 (.284 - .060) and significant at the 5% level.

Thus, the interaction effect between foreign R&D and education is positive in R&D-intensive industries in LAC countries but not in the non-LAC ones.[7]

What does this imply for the effect of education on TFP in LAC? A percentage point increase in education raises TFP by 5.55% in low R&D-intensity industries. For R&D-intensive industries in *LAC*, we also have an interaction effect of $\partial lnTFP / \partial E$ = 5.55 + .224(ln*NRD***DR***DLAC*). The average value of the latter variable for the R&D-intensive industries in LAC is 25 (somewhat higher than in the rest of the sample). Thus, the interaction effect equals 5.60. Thus, the total effect on TFP of a percentage point increase in education is 11.15 or twice the effect for the low R&D-intensity industries.

In fact, the difference between the two effects may be even larger. The reason is that education and TFP have mutually reinforcing effects in R&D-intensive industries, implying a potential *virtuous growth cycle* in LAC. The mechanism is as follows. An increase in education raises TFP in all industries but it raises TFP in R&D-intensive industries 100% more because of the interaction effect. The relative increase in the productivity of R&D-intensive industries *raises* the demand for skilled labor, which is used intensively in these industries and is complementary with technology.[8] This leads to further (possibly private) investments in education, further increases in the TFP of R&D-intensive industries relative to low R&D-intensity industries, further increase in the demand for skilled labor, and so on.

[7] We also tried interaction effects between education and foreign R&D for low R&D-intensity industries but these turned out not to be significant. This should not be surprising. Education reflects the capacity of the LAC country to absorb knowledge from the North and transform it into higher productivity and absorptive capacity is clearly more important in R&D-intensive than in low R&D-intensity industries.

[8] A strong positive impact of increases in technology on the demand for skilled workers is found by Abowd et al. (2007) for the US.

An increase in openness raises the level of foreign R&D (*NRD*). In the case of R&D-intensive industries in LAC, foreign R&D (ln*NRD***DR***DLAC*) interacts positively with education, with an effect on TFP of .224. This implies that the positive impact of education on TFP in LAC's R&D-intensive industries increases with the degree of openness, and so does the impact on TFP growth in the virtuous growth cycle. Thus, the quantitative importance of the virtuous growth cycle described above rises with openness. For instance, if openness (say) doubles uniformly across all R&D-intensive industries in all LAC countries, the interaction effect of education on TFP doubles as well.

So far, we have found that in the case of LAC countries, education and foreign technological knowledge (as measured by R&D stocks) are mutually reinforcing in their effect on TFP in R&D-intensive industries. Second, from the construction of foreign R&D, the results for LAC imply that education and openness are also mutually reinforcing in their impact on TFP in R&D-intensive industries.

Third, these results imply that *education can have a permanent effect on TFP growth* in R&D-intensive industries in LAC, even in the absence of a virtuous growth cycle. So far, we have abstracted from the growth of R&D stocks in the OECD. As R&D stocks in OECD countries increase over time, foreign R&D in all industries, including in R&D-intensive industries in LAC (*NRD*DR*DLAC*), rises as well. Assume that foreign R&D rises at a continuous rate of 5% per year because of the increase in OECD R&D stocks. This 10% increase in *NRD*DR*DLAC* has an impact on the growth of TFP equal to .05 of .224*E or .0112*E. Thus, the growth rate of TFP in R&D-intensive industries in LAC rises with education, with an increase in education of one year in a country with an average of 6 years of education (with a 16.7 percentage increase in education, raising

TFP growth by.167% per year). In other words, growth of knowledge in the North translates in higher growth rates in LAC's R&D-intensive industries when the absorptive capacity (i.e., education level) in LAC is higher.

How large is the interaction effect for the individual LAC countries? The interaction effect is equal to .224*(*lnNRD*DR*DLAC*E*), and the total effect of education on TFP is equal to 5.55*E* for low R&D-intensity industries, and is 11.15*E* for R&D-intensive industries. This effect varies by country according to the variation in foreign knowledge (*NRD*) and education (*E*). The average level of *lnNRD* (averaged over time and R&D-intensive industries) varies little across *LAC* countries but the average education level does. The secondary school completion ratio for 1998 varies from lows of 2.53% in Guatemala, 4.33% in Venezuela, 6.20% in Bolivia, 7.97% in Ecuador and 8.43% in Colombia, to highs of 12.33% in Trinidad and Tobago, 12.93% in Mexico, 15.0% in Chile and 16.2% in Panama.

With the values of education and *lnNRD*, we can derive the country-specific effect of education for low R&D-intensity industries and for R&D-intensive industries. These are shown in Table 3. As can be seen, the total effect of education on TFP varies from a low of 27.4% in Guatemala and 46.0% in Venezuela for R&D-intensive industries to a high of 162% for Chile and 180.2% for Panama, with the cross-country differences essentially determined by the difference in the level of education. The average effect of education on TFP in low R&D-intensity (R&D-intensive) industries in LAC is 55% (104%). Thus, education's average impact on TFP in low R&D-intensity industries is slightly over half (53%) of its impact in R&D-intensive industries.

Moreover, for a given rate of growth of NRD, the impact of a one-percentage-point increase in education on the growth rate of TFP for R&D-intensive industries is about the same in all LAC countries. However, a one-percentage-point increase in the level of education implies a much larger proportional increase for some countries than for others. For instance, it amounts to a 39.5% increase for Guatemala while it amounts to a 6.2% increase in Panama. Assuming that all LAC countries raise the level of education by 1% rather than 1 percentage point, the effects on the growth rate of TFP—assuming that *NRD* in R&D-intensive industries grows at 10% per year—is .05% for Guatemala, .09% in Venezuela, .13% in Bolivia, .16% in Ecuador, .17% in Colombia, .25% in Trinidad and Tobago, .27% in Mexico, .31% in Chile and .33% in Panama. These effects may appear small, but note that they are permanent productivity growth effects and because education can be raised by more than 1% over time.

4.2. Interaction with Governance

We now turn to column (ii). This column is similar to column (i) except for the fact that interaction effects are with respect to governance rather than with education. Governance has a direct positive and statistically significant effect on TFP. It also interacts positively and significantly with foreign knowledge in LAC's R&D-intensive industries, with a coefficient equal to .015 (.033 - .018).

The effect of governance on TFP in R&D-intensive industries in LAC is $\partial \ln TFP / \partial G$ = .798 + .015ln*NRD***DR***DLAC*. With an average value for ln*NRD* in R&D-intensive in LAC equal to 25 and little variation across countries, the effect is equal to .798 + .375**DR***DLAC*. The range from the lowest to the highest value of the governance index is 1.378 (see below). Assume that a country were to raise its governance index by .1 (about 7% of the range between the lowest and highest value). The impact would then be an 8% (.0798) increase in TFP for low R&D-intensity industries and a 12% (.1173) increase in TFP for R&D-intensive industries.

The index of quality of governance in LAC ranges from -.504 in Guatemala, -.408 in Colombia, -.369 in Venezuela, -.321 in Ecuador, -.071 in Mexico, to .018 in Bolivia, .115 in Panama, .589 in Trinidad and Tobago, and .874 in Chile. If Guatemala were to raise the quality of its governance to that of Chile (i.e., by 1.378), its TFP would rise by 1.10 (=.798*1.378) or by 110% in low R&D-intensity industries, and by 1.62 (= (.798+.375)*1.378) or by 162% in R&D-intensive industries.

Note that there is a *virtuous growth cycle* here as well. An increase in—i.e., an improvement in the quality of--governance raises TFP in all industries, though more so in R&D-intensive industries. The higher productivity raises the value of good governance [including the rule of law (enforceability of contracts, respect for property rights, crime incidence, effectiveness of the judiciary), political stability, credibility of policy commitments, and incidence of corruption]. The greater benefit of good governance raises the demand for, and equilibrium level of, governance. This has a further positive impact on TFP, which results in a further increase in the demand for governance, and so forth. Note also that this virtuous growth cycle is stronger for R&D-intensive industries.

4.3. Interaction with Both Education and Governance

Turning now to the combination of the effects of education and governance, column (iii) shows the interaction effect of the three variables education, governance and foreign R&D for R&D-intensive industries in LAC. Once again, the results on education and governance presented above carry through, and the interaction effect is equal to .241.

Surprisingly, the impact of the interaction of education and governance in R&D-intensive industries is the sum of the separate interaction effects of education and of governance in R&D-intensive industries, both in the case of non-LAC countries (-.0604 - .0123 = -.073) and of LAC countries (.2243 + .0263 = .241). That the interaction effect of education and governance on TFP in R&D-intensive industries is greater than the individual effect of either variable is an important confirmation of the importance of the two variables and of the fact that each one reinforces the impact of the other. What is more surprising is that the interaction effect turns out to be the exact sum of the individual effects of the two variables.

Thus, the above regression results lead to the additional implication that increases in both education and governance have permanent effects on TFP growth and they are mutually reinforcing. Moreover, the virtuous growth cycles are mutually reinforcing as well. Another implication is that, at least as far as R&D-intensive industries in LAC are concerned, simultaneous (and thus coordinated) policy reforms that result in improvements in education, governance and trade enhance developing countries' TFP growth to an extent that could not be attained through policy reforms affecting only a single or two of the three policy variables.

5. Conclusion

This paper focused on trade-related technology diffusion, education and governance, and on their impact on productivity growth in Latin America and the Caribbean (LAC), with the analysis conducted at the industry level. We obtained the following results:

North-South trade-related technology diffusion (foreign R&D) has a large positive impact on TFP in non-LAC countries but not in LAC countries. We further found that education and governance have a positive impact on TFP that is several times larger in LAC than in non-LAC countries. The smaller TFP effect of foreign R&D and the larger effect of education and governance suggest interaction effects between the former and the latter.

Moreover, both education and governance have a positive interaction effect with foreign R&D in R&D-intensive industries in LAC but not in non-LAC countries. This implies that the increase in education or governance raises TFP growth in LAC's R&D-intensive industries, and that this effect is larger the more open the economy.

These results imply various virtuous growth cycles with respect to education, governance and openness in LAC's R&D-intensive industries, as described below:

1. Human capital and R&D are complements in production. Thus, industries that are intensive in R&D tend to be intensive in human capital as well. Since an increase in education raises TFP in R&D-intensive industries relative to non-intensive industries, it follows that the return to education in the R&D-intensive industries increases relatively more. This raises the incentive to acquire additional education, which again raises TFP in

R&D-intensive industries absolutely as well as relative to non-intensive ones, which again raises the incentive to acquire education, etc.

2. A second virtuous cycle is associated with the fact that an increase in education E raises the return to NRD in R&D-intensive industries (dTFP/dNRD = a + b*E (b > 0) increases with E) and thus raises the incentive to acquire more NRD. Since NRD is defined as a trade-weighted sum of the R&D stocks of a country's trading partners, one way to increase it is through greater openness to trade, i.e., through trade liberalization. Hence, the incentive to open up the economy increases. Opening up to trade raises the return to education in R&D-intensive industries, which provides an incentive to acquire more of it, which again raises the return to openness in these industries, and both increases in E and openness raise TFP, which again raises the incentives to acquire more of them, etc. Note that the incentive to improve governance increases together with increases in openness and education.

3. The first and second virtuous cycles, which hold for increases in education, also hold for improvements in governance (increases in G) and for increases in the product of education and governance (E*G) as the increase in one of the two variables raises the impact of the other variable on TFP.

4. Virtuous cycles can also be generated through an initial increase in the degree of openness which raises the impact on TFP of E, G and E*G in R&D-intensive industries in LAC. In other words, any increase in E*G*NRD. An increase in openness results in an increase in NRD, but so does an increase in the R&D stocks of a country’s trading partners.

5. Note also that virtuous growth cycles may be generated through exogenous forces such as an increase in the rate of growth of R&D in trading partner countries.

What about vicious circles? It is important to note that the reinforcing effects of education, governance and trade also work in the opposite direction. For instance, a country suffering from a negative economic shock, say a reduction in its terms of trade, might decide to reduce its imports by raising import barriers. This would lead to a reduction in *NRD* which, because of the interaction effects, would be likely to reduce the impact of education and governance and thus reduce the incentive to invest in them. Hence, TFP growth would likely decline by more than expected when accounting only for the impact of the variable examined, possibly resulting in vicious circles. Note that TFP growth might also decline if trading partner countries suffered a negative shock that reduced their investment in R&D, thereby lowering the growth rate of their R&D stocks.

From the *policy* perspective, the paper's results suggest that authorities in LAC countries have an additional incentive to invest in education because of its direct as well as indirect impact (through interaction effects) on TFP growth, especially in R&D-intensive industries. Similarly, authorities have an additional incentive to improve governance and to open up the economy. Given all the positive interaction effects between education, governance and openness, LAC countries would gain most if the authorities increased the three policy variables simultaneously.

Virtuous cycles also obtain with increases in the R&D stocks of LAC countries' trading partners. Thus, the TFP growth impact of an increase in openness is likely to be greater for an increase in openness with trading partners that are technologically more advanced (with large R&D stocks) than with trading partners that are lagging technologically (low R&D stocks). Consequently, from the viewpoint of technology diffusion and productivity growth, it would seem more advantageous for LAC countries to enter into North-South rather than South-South regional trade agreements as the former are likely to generate greater international flows of technological knowledge than the latter (Schiff and Wang, 2006).

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Table 1. The Impact of Trade, Foreign R&D, Education and Governance on log TFP in LAC

Variables	(i)	(ii)
ln*NRD*	**0.248** ***(7.40)******	**0.264** ***(6.39)******
ln*NRD*DLAC*	**-0.221** ***(-4.46)******	**-0.243** ***(-6.06)******
ln*NRD*DR*		**0.081** ***(2.11)*****
ln*NRD*DR*DLAC*		**0.028** ***(3.87)******
E	**4.592** ***(2.76)******	**3.988** ***(2.51)*****
E*DLAC	**12.301** ***(3.50)******	**11.641** ***(3.85)******
G	**0.656** ***(3.11)******	**0.658** ***(3.21)******
G*DLAC	**2.579** ***(1.93)****	**4.478** ***(3.50)******
Adjusted R^2	**0.24**	**0.25**
Observations	**6948**	**6948**

Note: Figures in parentheses are t-statistics. Significance levels of 1%, 5% and 10% are indicated by ***, ** and * respectively. Regression results on country, year and industry dummies, and the constant, are not reported. *NRD* is the trade-related North-foreign R&D. *DR* = 1 for R&D-intensive industries and *DR*= 0 for low R&D-intensity industries. *DLAC*=1 for Latin American and Caribbean countries and *DLAC*=0 for non-LAC countries. *E* is the secondary school completion ratio for the population aged 25+. *G* is the average of the six governance indicators described in Section 3.

Table 2. Determinants of log TFP in LAC with Interaction Effects

Variables	(i)	(ii)	(iii)
ln*NRD*	**0.264**	**0.277**	**0.272**
	(6.00)*	***(6.32)****	***(3.21)****
ln*NRD*DLAC*	**-0.242**	**-0.234**	**-0.236**
	(-5.20)*	***(-5.12)****	***(-4.33)****
ln*NRD*DR*	**0.105**	**0.098**	**0.094**
	(2.38)	***(2.34)***	***(1.19)***
ln*NRD*DR*DLAC*	**-0.001**	**0.026**	**0.043**
	(-0.06)	***(3.02)****	***(2.44)***
E	**5.553**	**5.414**	**3.474**
	(3.68)*	***(3.68)****	***(1.56)***
ln*NRD*DR*E*	**-0.060**		
	(-1.42)		
ln*NRD*DR*E*DLAC	**0.284**		
	(2.14)		
G	**0.686**	**0.796**	**0.062**
	(2.61)	***(3.12)****	***(0.16)***
ln*NRD*DR*G*		**-0.012**	
		(-2.73)*	
ln*NRD*DR*G*DLAC*		**0.038**	
		(2.86)*	
E*G			**8.692**
			(3.60)***
ln*NRD*DR*E*G*			**-0.073**
			(-1.19)
ln*NRD*DR*E*G*DLAC*			**0.314**
			(2.89)*
Adjusted R^2	**0.25**	**0.25**	**0.25**
Observations	**6948**	**6948**	**6948**

Note: Figures in parentheses are t-statistics. Significance levels of 1%, 5% and 10% are indicated by ***, ** and * respectively. Regression results on country, year and industry dummies, and the constant, are not reported. *NRD* is the trade-related North-foreign R&D. *DR* = 1 for R&D-intensive industries and *DR*= 0 for low R&D-intensity industries. *DLAC*=1 for Latin America countries and *DLAC*=0 for non-Latin America countries. *E* is the secondary school completion ratio for the population aged 25+. *G* is the average of six governance indicators described in Section 3.

Table 3: Effect of Education on TFP (in %)*

	(1) *Low R&D-intensity industries*	*(2)* *Interaction effect with DR*	*(3)=(1)+(2)* *R&D-intensive industries*
Bolivia	35.3	33.6	68.9
Chile	86.4	75.6	162.0
Colombia	48.5	41.1	89.6
Ecuador	46.4	41.0	87.4
Guatemala	14.4	13.0	27.4
México	74.2	65.3	139.5
Panama	94.0	86.2	180.2
Trinidad & Tobago	71.6	64.5	136.1
Venezuela	25.0	21.0	46.0

* The effect on TFP is from a one percentage point increase in the level of education.