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ABSTRACT

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

This paper examines the impact on *TFP* in Latin America and the Caribbean (LAC) and in other developing countries (DEV) of trade-related foreign R&D (*NRD*), education and governance. The measures of *NRD* are constructed based on industry-specific R&D in the North, North-South trade patterns, and input-output relations in the South. The main findings are: i) education and governance have a much larger direct effect on *TFP* in LAC than in DEV, while the opposite holds for the North's R&D; and ii) education and governance have an additional impact on *TFP* in R&D-intensive industries through their interaction with *NRD* in LAC but not in DEV. These interaction effects imply that increasing the level of any of the three policy variables – education, governance or openness – result in virtuous growth cycles. These are smallest under an increase in trade, education or governance, are stronger under an increase in two of these three policy variables, and are strongest under an increase in all three variables.

JEL Classification: F15, O19, O33

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1. Introduction

This paper aims to examine the impact of policy on the international diffusion of technological knowledge in Latin America and the Caribbean (LAC). 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. In addition to trade, we also examine the importance of education and governance for productivity and for the impact of foreign R&D and openness on productivity.

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 (partly to low pay of public sector employees which attracts lower-ability individuals or able ones who then work elsewhere to make ends meet) would reduce the impact on TFP of the diffusion of technology and 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. As goods embody technological know-how, 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}, the industry-*j* 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*.

[1] In 1990, 96% of the world's R&D expenditures took place in industrial countries (Coe et al., 1997). 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.

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 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:

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

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:

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

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 the 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:

$$ln TFP_{cit} = \beta_0 + (\beta_N + \alpha_N DLAC) ln NRD_{cit} + \beta_E E_{ct} + \beta_G G_c$$

$$+\sum_t \beta_t D_t + \sum_c \beta_c D_c + \sum_i \beta_i D_i + \varepsilon_{cit};\qquad (4)$$

We also estimate equation (4) with *DLAC* replacing $\sum_c \beta_c D_c$. And equation (3) becomes:

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

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

We also estimate equation (5) with *DR* replacing $\sum_i \beta_i D_i$ and *DLAC* replacing $\sum_c \beta_c D_c$. Finally, we also examine the interaction between education (or governance) and *NRD* to see if education (or governance) affects TFP not just directly but also by affecting the impact of *NRD* on TFP.

3. Definition of Variables and Data Sources

Our sample consists of 16 manufacturing industries in the 9 LAC countries being examined as well as in the other developing countries in our sample, over the period 1976-98. The 9 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.[3]

[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), and Europe (Cyprus, Poland).

[3] Easterly (2001, p. 186) argues that Brazil's restrictive trade policy hampered growth. He states "If the government is foolish enough to prohibit imports of machines, growth will suffer. For example, Brazil moved more slowly into the computer revolution than necessary because of a government ban on PC imports, a misguided attempt to promote the domestic PC industry, a classic attempt by vested interests to hijack technological progress."

The 16 industries consist of 6 R&D-intensive industries and 10 low R&D-intensity industries. [4] 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.[5]

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 1998 at either the two-, three- or four-digit level.[6] R&D flows cover all intramural business enterprise expenditures, converted into US dollars, and then deflated using US GDP

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[4] 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.

[5] The R&D intensity 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 0.004, 0.006, 0.007, 0.008, 0.011, 0.013, 0.018, 0.022, 0.024, 0.028, *0.079, 0.081, 0.081, 0.110, 0.116* and *0.185* respectively. The high R&D intensity industries are in Italics. The average R&D-intensity of the "high" cluster is 11% while that of the "low" cluster is 1.3% (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.

[6] 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 (1998). For each country-industry-year, the weights (bilateral openness shares—imports/value added) are derived from the World Bank database "Trade and Production 1976-1998" (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 1976-98, 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. This is taken from Barro-Lee (2000) which provides five-year averages for 1960-2000.

As for governance, we use an average of six measures.[7] 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, 1999a, 1999b). Values are for 1997. The range is smaller in our sample because it excludes industrial countries and many LDCs.

4. Estimation Results

Estimating the equations for LAC as part of the full sample of 25 countries provided better results than the estimation for each of the 9 LAC countries separately or for the

[7] 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.

group of 9 LAC countries. This makes sense since ignoring the information in the data from the non-LAC countries is likely to bias the estimation results.

Table 1 presents estimation results for LAC. Column (i) shows that the elasticity of TFP with respect to foreign R&D for low R&D-intensity industries is positive, small and non-significant. The elasticity of foreign R&D for non-LAC developing countries is .245, while that for LAC is .020 (.245 - .225). Column (ii) shows that the elasticity for R&D-intensive industries in LAC (.120) is larger than for low R&D-intensity industries (.007) and the same holds in the other developing countries (DEV) where the elasticity for R&D-intensive industries is equal to .342 > .257.

Column (i) shows that the elasticity of TFP with respect to education is greater for LAC then for DEV, with a value of 17.1 (= 4.6 + 12.5) for LAC and 4.6 for DEV. Similar results obtain for governance. The elasticity of TFP with respect to governance is 3.2 (.65 + 2.59) in LAC and .65 for non-LAC countries.

Column (ii) shows similar results to those of column (i) for education and governance. The above results indicate that the impact of the North's R&D diffused through North-South trade on TFP is smaller in LAC while the impact of education and governance is greater. This may indicate the possibility of interaction effects, 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 (iii) in Table 2, education is interacted with trade-related foreign R&D (*NRD*) in R&D-intensive industries (ln*NRD***DR***E* and ln*NRD***DR***DLAC***E*). The interaction effect for non-LAC countries is negative (-.062) but not significant, while the interaction effect for LAC countries is .216 (.278 - .062) and significant at the 5% level. Thus, the interaction effect between foreign R&D and education is positive for R&D-intensive industries in LAC but not in non-LAC countries.[8]

What does this imply for the effect of education on TFP in LAC? A percentage point increase in education raises TFP by 5.574% in R&D-scarce industries. For R&D-intensive industries, we also have an interaction effect of $\partial lnTFP / \partial E$ = 5.574 + .216ln*NRD**DR*DLAC*. The average value of the latter variable for the R&D-intensive industries in LAC is 24 (somewhat higher than in the rest of the sample). Thus, the interaction effect equals 4.94 (.206*24) and the total effect is 10.51 or close to 90% higher than that 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 by close to 90% 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.[9] This leads to further (possibly private) investments in education, further increases in the TFP of R&D-

[8] 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 industries than in low R&D-intensity industries.

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

intensive industries by 90% more than in low R&D-intensity industries, further increase in the demand for skilled labor, and so on.

An increase in openness raises the level of foreign R&D. 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 .216. This implies that the positive impact of education on TFP in R&D-intensive industries in LAC rises 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 (skills) and foreign knowledge (R&D) 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 10% 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 10% of .216*E or .0216*E. Thus, the growth rate of TFP in R&D-intensive industries in LAC rises with education. In other words, growth of knowledge in the North translates in higher growth rates in the 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 .216*ln*NRD***DR***DLAC***E*, and the total effect of education on TFP is equal to 5.574*E* for low R&D-intensity industries, and is (5.574*E* + .216*ln*NRD***DR***DLAC***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 countries but education does vary much across LAC countries. The secondary school completion ratio for 1998 varies from a low 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 ln*NRD*, 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 27.3% in Guatemala and 45.7% in Venezuela for R&D-intensive industries to a high of 162% for Chile and 179.9% for Panama. Given that NRD varies little across countries while education varies a lot, the cross-country differences are essentially determined by the difference in the level of education.

Moreover, for a given rate of growth of NRD, the impact of a 1 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 1 percentage point increase in the level of education implies a much larger proportional increase for some countries than for others. For instance, a 1 percentage point increase in education amounts to a 39.5% increase for Guatemala (whose education level is 2.53%), while it amounts to a 6.2% increase in Panama (where the level is 16.2%). 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 they are not because 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 (iv) in Table 2. This column is similar to column (iii) except 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 .023 (.035 - .012).

The effect of governance on TFP in R&D-intensive industries in LAC is $\partial \ln TFP / \partial G$ = .788 + .023ln*NRD***DR***DLAC*. With an average value for ln*NRD* in R&D-intensive in LAC equal to 24 and little variation across countries, the effect is equal to .788 + .552**DR***DLAC*. The range from the lowest value (Guatemala) to the highest value (Chile) 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% (.0788) increase in TFP for low R&D-intensity industries and a 13% (.1340) 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 1.09 (=.788*1.378) or by 109% in low R&D-intensity industries, and by 1.85 (= (.788+.552)*1.378) or by 185% 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.

Turning now to the combination of the effects of education and governance, column (v) shows the interaction effect of 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. Thus, these regression results lead to the additional implication that both increases in education and increases in governance have permanent effects on the growth of TFP and that these effects are mutually reinforcing. Moreover, the virtuous growth cycles themselves are mutually reinforcing. Another implication is that, at least as far as R&D-intensive industries in LAC are concerned, countries would benefit more from coordinated improvements in education, governance and trade policy, than by focusing on each policy individually.

5. Conclusion

This paper has focused on technology diffusion and its impact on productivity growth in Latin America and the Caribbean (LAC) and examined, inter alia, the impact of education and governance on TFP. The analysis is conducted at the industry level.

We find that North-South trade-related technology diffusion (*NRD*) has a large positive impact on TFP in non-LAC countries, and has no significant impact in R&D-scarce industries in LAC countries and a significant impact in R&D-intensive industries, though smaller than in non-LAC countries. We also find that education and governance have a positive impact on TFP which is several times larger in LAC than in non-LAC countries. The results for LAC suggest that interaction effects may exist.

Moreover, both education and governance interact positively with *NRD* in their impact on TFP in R&D-intensive industries in LAC but not in non-LAC countries. This implies that an increase in education and/or governance has a permanent effect on TFP growth in LAC's R&D-intensive industries, and that this effect is larger the more open is the economy. It also implies a virtuous growth cycle with respect to education in Latin America, as increases in education result in a substantially larger increase in productivity in R&D-intensive than in R&D-scarce industries, leading to an increase in the demand for skills, further increases in education, further productivity increases which are larger in R&D-intensive industries, further increases in the demand for skills, and so on.

Given the positive impact on TFP of the interaction between *NRD* and education and between *NRD* and governance in R&D-intensive industries in LAC, it follows that trade liberalization, which raises *NRD*, results in an increase in the TFP impact of education and governance in these industries. This raises the incentive to increase both the level of education and the quality of governance, thereby raising the impact of *NRD* on TFP. Hence, the incentive to open the economy further increases, which raises the return to education and governance in R&D-intensive industries. This provides an incentive to increase the level of education and governance, which again raises the return to openness in these industries, with increased openness further raising the return to education and governance in R&D-intensive industries, etc.

Thus, the virtuous cycle associated with an increase in education is reinforced by another virtuous cycle associated with an increase in openness, and the same holds for an initial increase in governance. In other words, an increase in any of the three variables – openness, education and governance – can lead to a virtuous growth cycle, though the strength of the growth cycle is greater in the case of an increase in two of the three variables and is strongest in the case of an increase in all three variables simultaneously.

From the policy perspective, the results suggest that authorities would have a greater incentive to invest in education, improve governance and open the economy than in the absence of the positive and mutually reinforcing interaction effects between these variables, and that the increased incentive would be highest with respect to a coordinated improvement in education, governance and trade policy.

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Table 1. The Impact of Education and Governance on log TFP in LAC

Variables	(i)	(ii)
ln*NRD*	**0.245**	**0.257**
	(7.39)*	***(6.50)****
ln*NRD*DLAC*	**-0.225**	**-0.250**
	(-4.46)*	***(-6.03)****
ln*NRD*DR*		**0.085**
		(2.05)
ln*NRD*DR*DLAC*		**0.028**
		(3.8)*
E	**4.587**	**3.979**
	(2.83)*	***(2.45)***
E*DLAC	**12.469**	**11.771**
	(3.48)*	***(3.81)****
G	**0.650**	**0.665**
	(3.22)*	***(3.25)****
G*DLAC	**2.589**	**4.484**
	(1.90)*	***(3.54)****
Adjusted R^2	**0.23**	**0.24**
Observations	**5822**	**5822**

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 Latin America, with Interaction Effects

Variables	(iii)	(iv)	(v)
ln*NRD*	**0.267**	**0.271**	**0.269**
	(6.05)*	***(6.29)****	***(3.11)****
ln*NRD*DLAC*	**-0.246**	**-0.241**	**-0.240**
	(-5.22)*	***(-5.03)****	***(-4.42)****
ln*NRD*DR*	**0.103**	**0.095**	**0.096**
	(2.38)	***(2.26)***	***(1.23)***
ln*NRD*DR*DLAC*	**-0.000**	**0.024**	**0.04**
	(-0.04)	***(2.96)****	***(2.38)***
E	**5.574**	**5.415**	**3.467**
	(3.64)*	***(3.58)****	***(1.57)***
ln*NRD*DR*E*	**-0.062**		
	(-1.46)		
ln*NRD*DR*DLAC*E*	**0.278**		
	(2.08)		
G	**0.693**	**0.788**	**0.060**
	(2.51)	***(2.95)****	***(0.12)***
ln*NRD*DR*G*		**-0.012**	
		(-2.64)*	
ln*NRD*DR*DLAC*G*		**0.035**	
		(2.78)*	
E*G			**8.943**
			(3.58)***
ln*NRD*DR*E*G*			**-0.069**
			(-1.29)
ln*NRD*DR*DLAC*E*G*			**0.310**
			(2.82)*
Adjusted R^2	**0.24**	**0.24**	**0.24**
Observations	**5822**	**5822**	**5822**

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 R&D-intensive industries (in %)*

	(1) *Low R&D-intensity industries*	*(2)* *Interaction effect with DR*	*(3)=(1)+(2)* *R&D-intensive industries*
Bolivia	35.8	33.5	69.3
Chile	86.7	75.3	162.0
Colombia	48.7	41.0	89.7
Ecuador	46.1	41.3	87.4
Guatemala	14.6	12.7	27.3
México	74.7	65.1	139.8
Panama	93.6	86.3	179.9
Trinidad & Tobago	71.2	64.7	135.9
Venezuela	25.0	20.7	45.7
Average	*55.1*	*48.0*	*103.1*

* The effect on TFP is from a 1 percent increase in the level of education.