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Technology Transfer and Economic Growth in Developing Countries: an Econometric Analysis

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Abstract

In this paper we investigate two potential channels of international technology transfer towards developing countries: trade and foreign direct investments. We study the extent to which, through these channels, research and development expenditures (R&D) performed by advanced countries affect total factor productivity (TFP) levels in a panel of 45 developing countries over the period 1980-2000. Paying particular attention to the potential spillovers effects stemming from human capital, we estimate a TFP equation using the FMOLS technique. Our findings show that both channels induce substantial technology transfer across countries. In addition each developing country, for a given amount of foreign R&D, enjoys bigger spillovers the higher its educational level.

JEL classification: O47, F12, F21.

Keywords: Technology transfer, Economic growth, Trade, FDI.

Contents

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1. Introduction[1]

Recent advances in growth theory, often departing from the perfect competition paradigm, endogenize technological change, making it the outcome of innovative activities performed by firms. Each innovation, being the result of dedicated investments in research and development (R&D) which will ultimately affect total factor productivity (TFP), gives the innovator monopoly power over its product.[2] In the *quality ladder* models innovation leads to a superior product (Aghion and Howitt (1998)). In *variety expanding* models it brings forth a new product (Grossman and Helpman (1991)). In those models that combine the vertical and horizontal dimension to eliminate *scale effects*, innovative activity essentially reduces production costs (Peretto and Smulders (2002)).

The evidence shows that innovative activities today are still highly concentrated in few industrial countries.[3] Generally, developing countries do not engage in relevant amounts of R&D. Most of the time they are technological followers whose technical progress eventually relies upon the ability to adopt and appropriate innovations produced by advanced countries[4].

Hence, understanding international technology spillovers becomes a crucial issue in explaining economic development.

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[2] The concept of TFP was first introduced by Solow (1956). The so called Solow's residual represents the amount of output that is left after we have taken into account the contribution of all the production factors. In Solow (1956) there was no other explanation for it than exogenous technological progress. In the new growth theory, instead, the forces that offset the inherent tendency of diminishing return to the accumulated factors are endogenous to the economic system.

[3] According to the National Science Foundation (2002), in 1998 about 80 per cent of world innovation activity was performed by only 7 developed countries. The United States accounted for roughly 40 per cent of world R&D expenditures, spending as much as the rest of the major advanced countries (G7) countries combined. Japan, the second largest R&D investing country, is responsible for about 18 per cent of world expenditure and the European Union for approximately 30 per cent. In terms of GDP, in 2000 Japan invested about 3 per cent in R&D, United States about 2.7 per cent and the European Union around 1.9 per cent. The business sector is the major R&D performer in each of the leading economies: in 2000 the industrial sector performed more than 70 percent in the United States and Japan, whereas in the European countries above 60 percent. Within the business sector, manufacturing firms performs more than 90 per cent of industrial R&D in Japan, more than 80 per cent in European Union and almost 70 per cent in United States. Machinery and transport equipment and, to a less extent, the chemical industry account by far for the largest amount of R&D.

[4] See Grossman and Helpman (1991).

As we described more extensively in our previous work (Crispolti and Marconi (2003)), many theoretical and empirical studies investigate the channels through which international technology transfers occur and the country specific factors that may spur them. According to this literature three channels have been singled out: (i) *international trade of capital goods*, (ii) *international direct investments* (FDI) and (iii) *international trade in technology* recorded by payments for royalties and license fees. Through these channels, each developing country may benefit of *passive* or *active spillovers*.

Passive spillovers generally arise through the import of more specialized capital goods from developed countries. So that, TFP increases simply because a greater variety of specialized inputs are employed in the production process.

Active technological spillovers, instead, occur when innovation and learning are primarily conscious and purposive. That is, when local firms do not merely adopt, but also possess the *technological capability* to master and eventually improve upon technologies conceived in other countries, thereby improving domestic production and inventive activity.[5]

As argued by many authors, the absorption of foreign technology depends upon the capabilities of the host country, which, among other things, is affected by the domestic human capital stock. Namely, there may exist a human capital threshold below which developing countries are not able to capture the benefits associated with any of the transmission channels.[6]

Due to the scarcity of data on royalties and licence fees, in this paper we concentrate our analysis on the role played by capital goods trade and FDI in transferring technology across countries. Whereas most of the studies on this field focus on technology spillovers among advanced countries, we test for the existence of spillovers from advanced countries towards developing countries.[7] Following and extending the empirical work of Coe et al.(1997), we

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[5] FDI are generally considered the channel through wich active technology spillovers may actually occurs. Some authors, however, argued that trade may also contribute to active technology spillovers: by exposing domestic firms to new products, it may help reverse engeneering and induce innovation or imitation by the local competitors (see for example Grossman and Helpman (1991) and Connolly (2003)).

[6] See Saggi (2000), Mayer (2001) and OECD (2001).

[7] International R&D spillover literature mainly studies technology transfer among developed countries (see for example Coe and Helpman (1995), Van Pottelsberge de la Potterie and Lichtenberg (2001), Xu and Wang (1999)). Some attempts to include developing countries in such an analysis were made by Coe at al. (1997), Bayoumi and Xu and Wang (2001).

analyze how developing countries' TFP levels react to R&D expenditures performed by United States, Japan and the European Union (TRIAD).

Our paper contributes to the existing empirical literature in two aspects: (i) it investigates the long-run relation between TFP and the R&D intensity of machinery imports and FDI, at first considered separately and then jointly.[8,9] (ii) It explicitly takes into account the role of human capital in supporting technological spillovers.

Our findings suggest that trade and FDI induce a process of technology transmission from TRIAD's economies to developing countries. Moreover, we observe evidence of a significant interaction between the level of education in each developing country and the channels of transmission at stake. Namely, our data support the belief that the average level of education attained by a country is an important element for it to benefit from international technology spillovers.

The paper unfolds as follow: next section sketches a simple benchmark model of technology transmission in order to point out the main aspects involved in the international technology transfer process. Section 3 presents the econometric model which is estimated to test for international technology transfer through the trade and FDI channels. A brief review of our data is presented in section 4. Section 5 reports our empirical findings. Section 6 is devoted to the robustness analysis and section 7 concludes.

2. An illustrative model of technology transfer

This section draws from section 3 of our companion paper (Crispolti and Marconi (2003)) where we developed a simple production framework upon which we base our empirical analysis. Our aim is to show explicitly the role of active and passive technology spillovers on TFP.

Let's consider a small open developing economy, which faces a perfectly elastic demand in world markets and prices exogenously given.[10] For simplicity, we assume that the country

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[8] See Keller (2002) for an exhaustive review of theoretical and econometric contributions.

[9] Recent studies on technology transfers towards developing countries only draw attention to the trade channel, neglecting the potential benefits stemming from the FDI channel (see for example Coe et al. (1997)).

[10] The assumption of small open economy appears quite reasonable in the case of developing countries. "*This allow us to study the channels through which world markets influence domestic behavior without our needing to*

has one primary factor of production in fixed supply (labor), which is allocated over three activities: (i) the production of the final good, (ii) the manufacturing of intermediate goods and (iii) research. While the final good sector produces a homogenous good under perfect competition, the intermediate good sector supplies differentiated inputs (i.e. distinct varieties) each of them manufactured by a single monopolistic firm. Intermediate goods are traded and the producing firms may be owned by national or foreign investors. Foreign inventors have three choices: 1) produce the new variety by themselves in the home country and then export it (trade channel); 2) produce the new variety in the developing country and sell it in the market and abroad (FDI); 3) sell the licence to a firm owned by residents of the developing country (licensing). We assume that from the inventor's point of view the three alternatives are equivalent, that is, in any event the inventor appropriates the discounted value of future profits stemming from the production of the intermediate input. The intermediate goods firms control and accumulate firm specific knowledge which, by improving labor productivity, reduces the unit production cost. The firm specific knowledge is increased by allocating labor to the R&D sector and it is only partially appropriable. Namely, we assume that while it provides the exclusive right to produce an intermediate good (i.e. monopoly profits), at the same time, spilling over the whole economy, it increases the general purpose knowledge stock which everyone else can access to. Finally firms do not internalize their contribution to the general purpose knowledge stock.

Formally, the production function of the final good has the following Cobb-Douglas structure:

(1) $$Y = (RL_y)^{1-\alpha} \sum_{i=1}^{n} x_i^{\alpha} \text{ with } 0 < \alpha < 1,$$

where x_i is the i-th intermediate input, L_y is the number of workers employed in the final good sector and R is the general purpose knowledge stock available in this economy.[11] The j-th intermediate's firm produces inputs and invests in knowledge capital according to the following equations:

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worry initially about the reverse feedback relationships" (Grossman and Helpman (1991), chapter 6, page 144).

[11] In literature there are several ways of modelling it. For instance, by a weighted sum of the specific knowledge stocks belonging to all domestic and foreign firms operating in the economy, that is:

$$x_j = R_j L_{xj}, \tag{2}$$

$$\dot{R}_j = f\left(R_j, R, h_j\right) \text{ with } 0 < \beta < 1. \tag{3}$$

Labor productivity in the intermediate goods sector coincides with the firm-specific stock of knowledge, R_j, each firm can increase it investing in knowledge formation, $\dot{R}_j$, which builds on firm-specific knowledge, general purpose knowledge and human capital (h). By increasing their knowledge stock, firms improve their technology, reducing the cost of producing one unit of output. We can think of the role of human capital as one that allow not only the accumulation of this firm specific stock but also the diffusion of part of this knowledge to the rest of the economy, to form the general purpose stock.[12]

In order to keep the analysis extremely simple, we assume that all the firms operating in the economy are able to sell their goods at the same price, which must also be equal to the international price.[13] Since all intermediate inputs enter symmetrically in the final good production function and, in equilibrium, each variety bears the same price, inputs will be employed in the same quantity (i.e. $X = nx$). Using this assumption we can rewrite (1) as:

$$Y = (nR)^{1-\alpha} L_y^{1-\alpha} X^{\alpha}, \tag{4}$$

$$R = \sum_{j=1}^{n_d} \omega_j R_j; \ \sum_{j=1}^{n_d} \omega_j = 1,$$

see Peretto and Smulders (2002) for further details.

[12] On the formation of a general purpose knowledge stock see Romer (1990).

[13] We could assume that the firms are symmetric (i.e. they have exactly the same production functions and face the same production costs), or we could introduce some kind of labor market segmentation that would allow us to have different wages to compensate for productivity differences. Since this is not the focus of our research, we would leave the choice open.

from which

$$TFP = (nR)^{1-\alpha}\,. \tag{5}$$

Therefore, total factor productivity is a function of the number of varieties employed in production (*passive* spillovers) and the stock of accumulated knowledge (*active* spillovers). Notice that, while the number of varieties can be easily increased through international trade, knowledge rises only if the country is actively involved in the production of technological advanced goods or is able to capture and absorb foreign knowledge. Equation (4) and (5) will be our theoretical benchmark in the empirical analysis.

3. Empirical implementation

In this section we estimate an empirical equation implied by the theoretical benchmark model outlined in section 2. Ideally we would like to work on firm or industry level data, but since they are not available, at least for a relevant sample of developing countries, we must rely on aggregate data.

Equation (5) points out that TFP ultimately hinges upon the levels and the dynamics of two crucial variables, namely the varieties of intermediate goods, n, and the accumulated general purpose knowledge, R. Since both n and R are the outcome of cumulative past research efforts reflecting past investments in R&D, it follows that TFP is eventually affected by the R&D capital stock.[14]

Therefore, in order to ascertain whether trade in capital goods and inward FDI make technology spill over internationally we set up an econometric model based on equation (5) and investigates the impact of TRIAD's R&D stocks on developing countries' TFPs.

Our approach links TFP's movements to proxies for the R&D content of imports and FDI and to their interactions with a proxy of human capital investment: the domestic average

[14] See Coe and Helpman (1995) for more details on the relationship between n and the R&D effort.

years of schooling, as calculated by Barro and Lee (2000) and Cohen and Soto (2001) over the population of age 15 and plus.[15]

Our analysis follows the traditional international R&D spillover equation approach. Hence, to test for trade and inward FDI as technology transfer channels, we estimate the following equation:

$$(6) \quad \ln TFP_{it} = \alpha_i + \delta_t + \beta_1 \ln R_{it}^{trade} + \beta_2 h_{it} \ln R_{it}^{trade} + \\ + \beta_3 \ln R_{it}^{fdi} + \beta_4 h_{it} \ln R_{it}^{fdi} + \beta_5 h_{it} + \epsilon_{it},$$

where α_i and δ_t represent respectively the country-specific and time-specific dummies. R_{it}^{trade} and R_{it}^{fdi} are our measures for the foreign R&D capital stock which each developing country, by means of the trade and FDI channels, may access to. Finally, h_{it} is our proxy for the human capital stock and ϵ_{it} is an error term. Ideally the coefficients β_1 and β_3 would capture the passive spillovers, that is effects on n, whereas β_2 and β_4 would capture the active spillovers, such as those on R. The TFP measure is obtained according to the standard level accounting procedures, therefore following Collins and Bosworth (1996) we set:[16]

$$\widehat{TFP_{it}} = \left(\frac{\widehat{y}_{it}}{\widehat{x}_{it}^{\alpha}}\right); where\ \widehat{y} = Y/hL,\ \widehat{x} = X/hL\ and\ \alpha = 0.35.$$

Notice that the labor force is augmented to take into account the average years of schooling of the working population in each country.

Following Van Pottelsberghe de la Potterie and Lichtenberg (2001), our measures of foreign R&D capital stocks are given by the sum of the products between each TRIAD member

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[15] We are aware of the criticisms that can be raised on the use of such a measure as a proxy of changes in the stock of human capital (see for example Hanushek (2000)), or as a proxy of the stock itself, nevertheless this is the only measure available for a large group of developing countries and for a reasonable time length.

[16] Collins and Bosworth (1996) point out that a reasonable range for the capital share, α, is 0.3 to 0.4. OECD economies are generally closer to the lower bound, whereas developing countries to the upper. In order to minimize concern about the differences among the economies in the panel we follow the authors in setting α equal to 0.35.

R&D intensity and the bilateral capital good imports or the inward FDI positions respectively. That is:

$$(7) \qquad R_{it}^{trade} = \sum_j m_{ijt} \left(\frac{R_{jt}}{GDP_{jt}} \right) \text{ and } R_{it}^{fdi} = \sum_j f_{ijt} \left(\frac{R_{jt}}{GDP_{jt}} \right),$$
$$\text{with } i \in \{i...N\} \text{ and } j \in \{US, JP, EU\},$$

where m_{ijt} stands for the bilateral capital good imports of the i-th developing country from the j-th TRIAD's member at time t. Accordingly, f_{ijt} is the j-th TRIAD's country outward FDI stock in the i-th developing country at time t. Finally, the R&D intensity in the j-th advanced country at time t, (R_{jt}/GDP_{jt}), is given by the ratio of the j-th TRIAD member R&D capital stock and its GDP. As in Coe and Helpman (1995), the domestic R&D capital stock for each TRIAD's country is derived making use of the following perpetual inventory formula:[17]

$$R\&D_t^{stock} = (1-\delta)\, R\&D_{t-1}^{stock} + R\&D_t^{expenditure} \; where \; \delta = 0.05,$$

where the R&D expenditure is in real terms (see the appendix for more details).

Notice that, as in Coe et al. (1997), our econometric model implies that the R&D capital stock available to each developing countries reflects only the accessible foreign R&D capital stock. That is, we assume that domestic R&D expenditures in our sample developing countries are negligible. In the robustness section we will make some corrections to take into account the fact that, despite the lack of data, we know that some of these countries actually do perform relatively significant amounts of R&D.[18]

[17] Coe and Helpman (1995) obtain alternative measures of R&D capital stocks assuming the obsolescence rate, δ, equal to 0.1 and 0.15. Since their results do not change significantly, we stick to their first assumption (i.e. $\delta = 0.05$).

[18] See Coe et al. (1997) for further details and Mayer (2001) for a list of countries that register significant R&D expenditures.

4. Data

Our empirical results are based on a panel of 45 developing countries over the period 1980-2000. Data for all countries are summarized in table 1. Most of the variables used in the econometric analysis come from the Bosworth and Collins (1996) dataset, which provides yearly figures for real GDP (Y), real capital stock (X), labor force (L) and the average years of schooling (our proxy for the level of human capital h). TRIAD's figures on business sector R&D expenditures come from the OECD's *Main Scientific and Technological Indicators* database. Bilateral trade and FDI data come, respectively, from the UN's *ComTrade* dataset and from the UNCTAD's *FDI* dataset combined with the Eurostat's *NewCronos* figures.[19,20]

It is worth noting that there is a remarkable difference in the quality of data for each channel. While for the trade channel we consider bilateral imports of capital goods only, for the FDI channel such a breakdown is not available, forcing us to consider the whole amount of bilateral FDI stocks.

5. Empirical results

In tables 2 we report the regression results for different specifications of equations (6). According to the panel cointegration literature, estimating the coefficients of (6) involves some methodological issues related to the statistical properties of the variables at stake.[21] Namely, if variables are cointegrated the OLS estimator does not provide consistent estimates of the $\beta s.$ Kao and Chiang (2000) show that there are alternative econometric techniques which may be more promising in cointegrated panel regression.[22] Phillips and Moon (2000) and Pedroni (2004), extending a previous contribution by Phillips (1995), point out that the

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[19] As in Coe and and Helpman (1995) we use the bilateral imports of machinery and transport equipment (SITC 7, rev.2) as a proxy for the imports of capital goods.

[20] Since bilateral FDI data are not available for all relevant declaring and partner countries, we estimate them making use of both the Eurostat's database, which provides a regional breakdown for the TRIAD's FDI outward positions, and UNCTAD's dataset, which in turn supplies figures for the inward FDI positions in the relevant 45 developing countries (see the appendix for more details).

[21] See Baltagi (2001) and Phillips and Moon (1999) for a review.

[22] See also Baltagi and Kao (2000), Banerjee (1999) and Pedroni (1999).

Fully Modified Ordinary Least Square estimator (FMOLS) yields consistent estimates of the regression coefficients.

Since the variables in our panel turn out to be nonstationary and cointegrated, we estimate the coefficients of equation (6) by FMOLS, thus we are estimating a long-run relation between TFP and the R&D intensity of machinery imports and FDI[23,24]. In what follows we investigate the technology transfer issue, first looking at each channel of transmission separately, then at both channels simultaneously.

Trade channel

In regression (i) of table 2 we allow trade to be the only channel through which developing countries may enjoy a technology transfer. The coefficient of the trade foreign R&D capital stock turns out to be positive and within the range 0.04-0.26, which, in the field literature, is believed to characterize less industrialized economies (Coe et al. (1997), note 12, page 143). In regression (ii) we investigate the potential role played by human capital accumulated in each country. That is, we allow for the marginal effect of the foreign R&D measure to depend on the level of h by introducing an interaction term in (6).[25] Under this new specification, two distinct effects on TFP are considered: a direct one, captured by the coefficient β_1 in regression (i) and an indirect one, represented by β_2, which hinges upon the average level of education attained by each developing country. According to regression (ii) the trade foreign R&D capital stock continues to affect positively the TFP levels, but contrary to regression (i) such an effect is indirect (β_2 is significant and positive) rather than direct (β_1 is not significantly different from zero). Such a result would suggest that trading with advanced countries may not be enough in order to enjoy a technology transfer, and that the level of education, h, is relevant in determining the magnitude of the transfer.

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[23] The results of the unit root tests are reported in table 5.

[24] That is, the residuals of the regression are integrated of order zero. Following Van pottelsberghe de la Potterie and Lichtenberg (2001) and Kao et al. (1999), in order to check for the stationarity of the error term, we perform several tests recently developed by Pedroni (1995) and Pesaran (1997), exploiting both the time and country dimension. The results of such tests are presented in table 2 for each and every specification of equation (6).

[25] In this case the TFP elasticity to foreign R&D changes is given by $\beta_1 + \beta_2 * \overline{H}$, where $\overline{H}$ is some kind of average of H.

FDI channel

In regression (iii) we perform the same exercise on the FDI channel. Again, when we do not control for the educational levels, we find that the FDI foreign R&D measure has a significant and positive effect on the developing countries' TFPs. But, once we add such a control, the interaction term in regression (iv), we find again that the magnitude of the spillover on developing countries' TFPs depends on the level of education reached by the country. As in regression (ii), the direct effect of the FDI foreign R&D turns out to be statistically null, suggesting that attracting FDI is not sufficient to generate a technology transfer. On the contrary, the indirect effect is significant and positively signed, showing that h plays an important role in making the FDI foreign R&D variable effective.

In regressions (v) to (vi) we consider the two channels simultaneously, and, although, as we would expect, the coefficients associated to each channel and to the interaction terms are reduced, they are all sinificant, indicating that both channels do actually affect the TFP and that not taking them into account simultaneously may lead to overestimate their impact on TFP. Also, note that, while the coefficient on the FDI interaction is highly significant, that on the interaction with trade is significant olnly at the 10% level. This result suggest that the level of education may be particularly important for the FDI channel.[26]

6. Robustness

Table 3 presents the results of additional regressions run in order to check for the soundness of our results. In so doing we focus our attention to the case of on the two channels taken together.

Following the lines of Coe and Helpman (1995) and Grossman and Helpman (1991) our estimates of (6) may suffer from the exclusion of a control for the relative size of sample countries. Hence, what we have been capturing in regressions (v) to (vi) of table 2 might actually be a "size" effect, rather than the impact of a true exposure to foreign technology. We tackled this issue using the measure of real openness proposed by Alcalà and Ciccone

[26] For a discussion on the issues related to FDI data see Xu (2000). It is important to underline that the sectoral composition of FDI is likely to be fundamental in determining the potential of technology transfer, with FDI in high-tech sectors having a greater potential. As we will argue later on, countries may fundamentally differ in the sectoral composition of their FDI, with countries receiving FDI in technology advanced production and others in low-tech or resource based production. The evidence shows that what matters is not only the amount, but also the quality of FDI in assessing the possibility to appropriate of foreign technology.

(2004) as a proxy for the country size.[27] Columns (i) and (ii) report our results. Despite the introduction of a new variable, estimates of the two channel's effects are remarkably stable both in terms of coefficients and of total elasticities, meaning that developing countries do benefit from the exposure to foreign technology.

Columns (iii) and (iv) deal with another omitted variable issue. As mentioned in previous sections while estimating regression (6) we did not take into account developing countries domestic R&D expenditures. We argued that generally developing countries do not perform a significant R&D effort and even if so, data on the business sector R&D stocks are not available or highly incomplete for econometric analyses. Nevertheless some developing countries do perform a relatively significant R&D expenditure. Therefore, as suggested in Mayer (2001), we exclude from our sample those countries that are thought to undertake relevant domestic R&D efforts.[28] It is worth nothing that the excluded countries are also those with higher human capital levels. Results still provide evidence in favor of technology transfers through both channels, suggesting that neglecting domestic R&D efforts does not alter our results. However as we would expect, since the average level of human capital is lower, total elasticities of TFP to foreign R&D are significantly reduced, reinforcing the idea that countries with low human capital and negligible domestic R&D benefit less from technology transfers, especially through FDI.

In the remaining columns we check whether our findings are confirmed at regional level. Namely, we estimate (6) by region: Asia, Africa and Latin America. Columns (v) to (x) provide evidence in favor of our previous results, showing that the technology transfer occurs in all regions, though with some interesting differences. We find that in all regions, the trade related total elasticity of TFP to foreign R&D does not depend on human capital (i.e. β_2 is statistically null in all regions). Since trade in capital goods mostly involves passive spillovers, it might be the case that such a channel does not necessary need human capital to exert positive effects on TFP. On the contrary, except for the case of Asia, the positive effect of the FDI channel ultimately hinges on education, providing evidence of the existence of active

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[27] This measure of real openness variable is given by exports plus imports in US$ exchange rate over GDP in purchasing power parity US$ to take into account cross-country differences in the relative price of non-tradable goods. See Alcalà and Ciccone (2004) for more details.

[28] According to Mayer (2001) these countries are: Argentina, Brazil, Chile, China, India, Indonesia, Korea, Mexico, Pakistan, Singapore, Taiwan, Thailand and Venezuela.

spillovers. Such a result is particularly interesting. As we mentioned before, since we are not able to control for the sectoral composition of FDI, the heterogeneity of FDI figures may indeed hide very different realities that could ultimately lead to opposite conclusions in terms of technology transfer potential of this channel. This seems to be the case in our region-specific regressions. In Asia, where evidence at the regional level, suggest that most of the inward FDI are directed toward the manufacturing sector, we get positive direct and indirect effects of TRIAD's R&D on TFPs. On the contrary, in Latin America, where the largest portion of FDI goes to the tertiary sector (i.e. financial services and insurances), the overall positive effect of foreign R&D is granted only because human capital is relatively high on average.[29] Finally, in Africa, the region with the lowest level of human capital, the positive impact of the FDI is only through the interaction with human capital.[30]

7. Conclusion

Recent contributions to the growth theory point out the potential benefits for developing countries of importing capital goods and attracting FDI in order to increase their TFP.

Given that technological progress is the result of cumulative investments in R&D and that innovative activities are concentrated in few advanced economies, developing countries through capital good imports and inward FDI positions, may not only access to foreign technology, but also appropriate it.

In this paper we studied the extent to which R&D expenditures performed by the TRIAD's members affect TFP levels in a panel of 45 developing countries over the period 1980-2000. In so doing, we pay particular attention to the role of human capital in magnifiying or inhibiting technology spillovers to these countries. Our measure of human capital consists

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[29] See Crispolti and Marconi (2003) for a more accurate description of the available evidence on FDI geographical and sectoral breakdown.

[30] According to the spatial econometric theory our results may suffer from some sort of spatial dependence among countries of the panel, that can be modeled by means of a weights' matrix (see Anselin (1988)). We checked for that using the Stata routines spatwmat, spatreg and spatdiag written by M. Pisati. We constructed our matrix of of weights making use of the latitude and longitude measures provided by G. Clair, G. Gaulier, T. Mayer and S. Zignago [see www.cepii.fr/francgraph/bdd/distances.pdf for further information]. Although tests performed on the residuals from the OLS estimate of regression (6) show that there exists spatial dependence among countries, the results does not differ significantly from our FMOLS results, in particular the maximum likelihood estimates of all the relevant coefficients show the same signs and magnitudes of those from the FMOLS estimate. The results of these tests, which are not reported in the paper, are available from the authors upon request.

of the average level of education attained in each economy of the sample, the only proxy for human capital available for a large number of countries and for a reasonable time span.

Using the FMOLS technique we estimate a cointegrated equation of international R&D spillovers on TFP and we find that both channels (i.e. trade and FDI) induce a substantial technology transfer across countries. Moreover, for a given amount of foreign R&D capital stock, each developing country enjoys a bigger technology transfer the higher is its average years of schooling. That is, the R&D content of capital good imports and FDI has not only a positive direct effect, potentially equal for each country in the panel, but also an indirect one, which makes the overall effect on TFP differ among countries according to their level of education.

TABLES

Table 1

SUMMARY STATISTICS

Countries	TFP (1)	TFP(2)	Trade R&D capital stock	FDI R&D capital stock	Average year of education
			ratio 2000 to 1980		*average 1980-2000*
Argentina	0.87	0.97	0.84	8.75	7.78
Bangladesh	1.00	1.30	0.87	10.13	2.76
Bolivia	0.77	0.92	0.85	7.70	6.03
Brazil	0.64	0.90	2.45	7.21	4.99
Cameroon	0.64	0.83	0.39	2.44	3.40
Chile	1.25	1.36	1.75	31.00	7.91
China	2.16	2.46	5.91	36.28	5.23
Columbia	0.75	0.89	0.89	7.42	5.36
Cote d'Ivoire	0.53	0.89	0.44	4.12	2.35
Dominican Rep.	0.89	1.07	3.37	13.98	4.63
Ecuador	0.74	0.83	0.56	6.17	6.59
Egypt	0.75	1.26	1.04	5.88	4.51
El Salvador	0.67	0.87	4.29	8.18	4.30
Ghana	0.97	1.09	1.83	3.50	4.14
Guatemala	0.72	0.94	1.50	3.12	3.42
Honduras	0.65	0.82	1.24	10.30	4.41
India	1.15	1.51	2.02	10.46	3.73
Indonesia	0.77	1.00	1.46	3.84	4.90
Kenya	0.81	1.01	0.55	1.65	4.32
Korea	1.32	1.48	5.81	30.79	9.91
Madagascar	0.56	0.81	0.52	5.84	2.89
Malawi	0.99	1.31	0.33	3.13	3.04
Malaysia	1.00	1.19	4.72	6.64	6.77
Mali	0.73	1.00	0.80	26.04	0.80
Mexico	0.71	0.88	3.94	7.67	6.54
Mozambique	0.79	1.19	0.57	47.37	1.36
Nicaragua	0.49	0.66	1.79	8.07	4.46
Nigeria	0.45	0.85	0.23	5.35	2.64
Pakistan	0.89	1.31	0.66	6.49	3.28
Paraguay	0.67	0.75	1.25	3.73	5.81
Peru	0.66	0.77	1.01	7.06	6.92
Philippines	0.73	0.83	4.59	6.32	7.15
Rwanda	0.46	0.58	0.31	3.01	2.12
Senegal	0.87	1.13	1.11	3.62	2.07
Singapore	1.26	1.54	4.09	10.05	6.66
Sri Lanka	1.05	1.16	1.95	6.91	6.16
Taiwan	1.54	1.58	5.71	7.56	8.05
Thailand	1.06	1.37	5.30	16.24	5.74
Trinidad and Tobago	0.82	0.86	0.83	4.58	8.09
Tunisia	0.86	1.17	1.81	1.19	3.64
Uganda	1.07	1.52	0.76	86.31	2.69
Uruguay	0.91	1.04	0.96	1.84	7.13
Venezuela	0.76	0.83	0.79	10.75	5.80
Zambia	0.80	1.00	0.20	4.49	4.93
Zimbabwe	0.69	1.03	1.57	3.71	5.46
Maximum	2.16	2.46	5.91	86.31	9.91
Minimum	0.45	0.58	0.20	1.19	0.80
Average	0.86	1.08	1.86	11.26	4.91
Regional averages					
Africa (16 cnts)	0.73	1.02	0.64	3.27	3.15
Asia (12 cnts)	1.06	1.30	4.34	12.90	5.86
Latin America (17 cnts)	0.79	0.93	2.16	7.97	5.89

Table 2

TOTAL FACTOR PRODUCTIVITY RESULTS

Coefficients	**Variables**	**(i)**	**(ii)**	**(iii)**	**(iv)**	**(v)**	**(vi)**
	Trade channel						
β_1	$lnR\&D^{Trade}$	0.1784‡	0.0345			0.1602‡	0.0675†
β_2	$H * lnR\&D^{Trade}$		0.0215‡				0.0102♯
	FDI channel						
β_3	$lnR\&D^{FDI}$			0.1257‡	0.0289	0.0979‡	0.0600‡
β_4	$H * lnR\&D^{FDI}$				0.0234‡		0.0090†
	Control:						
	H	NO	YES	NO	YES	NO	YES
	R^2 $adjusted$	0.2669	0.3443	0.1443	0.2998	0.3543	0.4258
Total elasticity of TFP with respect to:							
$R\&D^{Trade}$ $(\beta_1 + \bar{H} * \beta_2)$		0.1784	0.1055	—	—	0.1602	0.1176
$R\&D^{FDI}$ $(\beta_3 + \bar{H} * \beta_4)$		—	—	0.1257	0.1148	0.0979	0.1042
Cointegration tests							
Pedroni's tests (1995)							
PC1		-17.4236‡	-17.2285‡	-17.2447‡	-19.2717‡	-19.3149‡	-19.0730‡
PC2		-17.0037‡	-16.8133‡	-16.8291‡	-18.8073‡	-18.8494‡	-18.6134‡
Pedroni's tests (1999)							
Panel ν-statistic		1.02120	0.22182	-0.06285	-0.00996	-0.16744	-1.54764
Panel ρ-statistic		-1.74228†	1.56105	0.07073	2.07764	0.81060	4.60410
Panel τ-statistic A		-3.88695‡	-3.31096‡	-2.32463‡	-3.10283‡	-2.95307‡	-6.05980‡
Panel τ-statistic B		-3.84764‡	-3.25837‡	-1.64402†	-5.02566‡	-2.73029‡	-4.18179‡
Group ρ-statistic		0.47586	4.06644	2.26439	5.01782	3.03797	7.30621
Group τ-statistic A		-3.47871‡	-4.24269‡	-2.14760‡	-2.37227‡	-2.85070‡	-7.26478‡
Group τ-statistic B		-3.30124‡	-4.99685‡	-2.84197‡	-6.91386‡	-3.22804‡	-4.93258‡
Kao's tests (1997)							
DF ρ-statistic		0.0808	0.3112	0.4675	-0.3541	-0.9052	-0.6053
DF τ_ρ-statistic		-12.9073‡	-9.2907‡	-11.3502‡	-10.5760‡	-13.8413‡	-10.8487‡
DF ρ^*-statistic		-7.9172‡	-7.4473‡	-7.2262‡	-8.3997‡	-9.4329‡	-8.8334‡
DF τ^*_ρ-statistic		-2.1268†	-0.1385	-1.2033	-1.0438	-3.3645‡	-1.2659
ADF (1 lag)		5.6192	5.6497	4.7712	4.3414	4.7812	4.9761

The dependent variable is ln(TFP). Regressions include unreported country and time specific effects. Definitions: H is the average year of schooling, $R\&D^{Trade}$ is the foreign R&D capital stock available through the trade channel, $R\&D^{Fdi}$ that through FDI. $\bar{H}$ is the H sample mean, $\bar{H} = 4.907757$. The *t*-statistics A is nonparametric, whereas B is parametric. ‡ indicates reject null hypothesis of no effects or no cointegration at 1% significance level, † at 5% level and ♯ at 10%.

Table 3

ROBUSTNESS ANALYSIS

Coefficients	Variables	real openess (i)	real openess (ii)	domestic R&D (iii)	domestic R&D (iv)
		n=45; t=21; NT=950		n=32; t=21; NT=672	
	Trade channel:				
β_1	$lnR\&D^{Trade}$	0.1652‡	0.0825‡	0.1263‡	0.0654♯
β_2	$H * lnR\&D^{Trade}$		0.0130†		0.0105♯
	FDI channel:				
β_3	$lnR\&D^{FDI}$	0.0937‡	0.0599‡	0.0552‡	0.0432†
β_4	$H * lnR\&D^{FDI}$		0.0094‡		0.0048
	Controls:				
β_5	H		-0.2282‡		-0.1595‡
β_6	$ln(real\ openess)$	-0.0741‡	-0.1186‡	-0.0518‡	-0.0741‡
	$R^2\ adjusted$	0.3727	0.4489	0.2180	0.2469
Total elasticity of TFP with respect to:					
$R\&D^{Trade}\ (\beta_1 + \bar{H} * \beta_2)$		0.1652	0.1463	0.1263	0.1115
$R\&D^{FDI}\ (\beta_3 + \bar{H} * \beta_4)$		0.0937	0.1060	0.0552	0.0432
$\bar{H}$ (average value)		4.907757		4.385465	
Cointegration tests:					
Pedroni's tests (1995)					
PC1		-19.6640‡	-19.7514‡	-16.8492‡	-16.5219‡
PC2		-19.1901‡	-19.2754‡	-16.4431‡	-16.1237‡
Kao's tests (1997)					
DF ρ-statistic		-1.1617	-0.9213	-0.9119	-0.7335
DF τ_ρ-statistic		-14.0048‡	-11.2099‡	-10.6143‡	-9.0781‡
DF ρ^*-statistic		-9.8757‡	-9.3381‡	-8.2485‡	-7.8857‡
DF τ^*_ρ-statistic		-3.6623‡	-1.6525†	-2.9315‡	-1.4042♯
ADF (1 lag)		4.7292	4.9471	4.0677	4.1543

The dependent variable is ln(TFP). Regressions include unreported country-specific and time-specific effects. Definitions: H is the average year of schooling, $R\&D^{Trade}$ is the foreign R&D capital stock available through the trade channel, $R\&D^{Fdi}$ that through FDI. $\bar{H}$ is the H sample mean. In regressions (iii) and (iv) the following countries were excluded from the panel: Argentina, Brazil, Chile, China, India, Indonesia, Korea, Mexico, Pakistan, Singapore, Taiwan, Thailand and Venezuela. ‡ indicates reject null hypothesis of no effects or no cointegration at 1% significance level, † at 5% level and ♯ at 10%.

ROBUSTNESS ANALYSIS

Coefficients	Variables	(vii)	(viii)	(ix)	(x)	(xi)	(xii)
		Asia		Latin America		Africa	
		n=12; t=21; NT=252		n=17; t=21; NT=357		n=16; t=21; NT=336	
	Trade channel:						
β_1	$lnR\&D^{Trade}$	0.2182‡	0.2380‡	0.1623‡	0.2239‡	0.1642‡	0.1826‡
β_2	$H*lnR\&D^{Trade}$		-0.0066		-0.0054		-0.0021
	FDI channel:						
β_3	$lnR\&D^{FDI}$	0.1572‡	0.0961‡	0.0638‡	-0.1123†	0.0731‡	0.0193
β_4	$H*lnR\&D^{FDI}$		0.0159‡		0.0285‡		0.0257‡
	Controls:						
β_5	H		-0.2687‡		-0.4331‡		-0.2006‡
β_6	$ln(real\ openess)$	-0.2414‡	-0.2387‡	-0.1860	-0.1074‡	-0.0080	-0.0350
	$R^2\ adjusted$	0.4780	0.6301	0.1811	0.5289	0.2694	0.3079
Total elasticity of TFP with respect to:							
$R\&D^{Trade}\ (\beta_1+\bar{H}*\beta_2)$		0.2182	0.2380	0.1623	0.2239	0.1642	0.1826
$R\&D^{FDI}\ (\beta_3+\bar{H}*\beta_4)$		0.1572	0.1893	0.0638	0.0556	0.0731	0.0809
$\bar{H}$ (average value)		5.861731		5.892495		3.145991	
Cointegration tests:							
Pedroni's tests (1995)							
PC1		-12.4427‡	-15.5707‡	-9.6328‡	-13.7609‡	-14.4686‡	-14.8782‡
PC2		-12.1429‡	-15.1955‡	-9.4007‡	-13.4293‡	-14.1199‡	-14.5196‡
Kao's tests (1997)							
DF ρ-statistic		-1.1598	-2.7332‡	0.0555	-1.7498†	-1.9059†	-2.0697†
DF τ_ρ-statistic		-8.5156‡	-7.2124‡	-7.8955‡	-7.0277‡	-8.2385‡	-7.4297‡
DF ρ^*-statistic		-5.8603‡	-7.7235‡	-4.8765‡	-7.6080‡	-7.8278‡	-8.0057‡
DF τ^*_ρ-statistic		-2.2612†	-2.5646‡	-1.5283♯	-1.5956♯	-3.1647‡	-2.2951†
ADF (1 lag)		1.4759	0.5482	3.3306	2.3728	2.3415	2.4016

The dependent variable is ln(TFP). Regressions include unreported country-specific and time-specific effects. Definitions: H is the average year of schooling, $R\&D^{Trade}$ is the foreign R&D capital stock available through the trade channel, $R\&D^{Fdi}$ that through FDI. $\bar{H}$ is the H sample mean. ‡ indicates reject null hypothesis of no effects or no cointegration at 1% significance level, † at 5% level and ♯ at 10%.

Table 4

SUMMARY STATISTICS

Variable	Mean		Std.Dev.	Min	Max	Observations
TFP	overall	-3.595	1.869	-7.402	0.388	N=945
	between		1.885	-7.223	0.059	n=45
	within		0.129	-4.327	-3.060	T=21
H	overall	4.908	2.078	0.613	11.138	N=945
	between		2.025	0.795	9.906	n=45
	within		0.552	3.032	6.436	T=21
R&D Trade	overall	5.222	1.742	1.475	9.420	N=945
	between		1.698	2.163	8.375	n=45
	within		0.462	3.717	6.490	T=21
R&D FDI	overall	5.811	2.010	-0.156	11.064	N=945
	between		1.893	2.010	9.116	n=45
	within		0.729	3.645	9.152	T=21
H*(R&D Trade)	overall	27.748	18.170	1.644	99.217	N=945
	between		17.496	2.346	80.166	n=45
	within		5.526	6.339	46.799	T=21
H*(R&D FDI)	overall	31.034	19.314	-0.450	104.149	N=945
	between		18.181	1.931	71.083	n=45
	within		7.036	9.353	64.100	T=21

UNIT ROOT TESTS

(Im-Pesaran-Shin test for cross-sectionally demeaned variables, lag average = 2)

Variables	**Deterministic chosen**	**t-bar**	**10%**	**5%**	**1%**
			critical values		
ln(TFP)	constant & time trend	-1.834	-2.33	-2.37	-2.45
H	constant & time trend	-1.597	-2.33	-2.37	-2.45
ln(R&D Trade)[31]	constant	-1.641	-1.69	-1.73	-1.82
ln(R&D FDI)	constant & time trend	-2.026	-2.33	-2.37	-2.45
H*ln(R&D Trade)	constant & time trend	-2.128	-2.33	-2.37	-2.45
H*ln(R&D FDI)	constant & time trend	-1.771	-2.33	-2.37	-2.45

[31] The null of nonstationarity was not rejected in presence of the constant and time trend, whereas it was rejected with the inclusion of the constant.

Table 6

CORRELATIONS BETWEEN VARIABLES

	TFP	H	R&D Trade	R&D FDI	H*(R&D Trade)	H*(R&D FDI)
TFP	1.000					
H	-0.180	1.000				
R&D Trade	-0.142	0.586	1.000			
R&D FDI	-0.197	0.603	0.858	1.000		
H*(R&D Trade)	-0.091	0.890	0.849	0.753	1.000	
H*(R&D FDI)	-0.126	0.911	0.793	0.832	0.960	1.000

Appendix

7.1 *FMOLS overview*

In this section we provide a brief review of the FMOLS estimator, for a complete overview the reader is referred to Baltagi and Kao (2000), Kao and Chiang (2000) and Phillips and Moon (2000).

Consider the following fixed effect panel regression:

$$y_{it} = \alpha_i + x'_{it}\beta + u_{it} \text{ with } i = 1, ..., N,\ t = 1, ..., T, \tag{8}$$

where $\{y_{it}\}$ are scalars, β is a $k \times 1$ vector of slopes, $\{\alpha_i\}$ are the country intercepts and $\{u_{it}\}$ are the stationary disturbance terms. Assuming that $\{x_{it}\}$ are $k \times 1$ processes integrated of order one for all i, that is:

$$x_{it} = x_{i(t-1)} + \varepsilon_{it}, \tag{9}$$

where ε_{it} is a white noise, equation (8) describes a system of cointegrated regressions. The OLS estimator for βs is given by:

$$\widehat{\beta}_{OLS} = \left[\sum_{i,t}^{N,T}(x_{it} - \overline{x}_i)(x_{it} - \overline{x}_i)'\right]^{-1}\left[\sum_{i,t}^{N,T}(x_{it} - \overline{x}_i)(y_{it} - \overline{y}_i)\right]. \tag{10}$$

Under the assumptions that $\{y_{it}, x_{it}\}$ are independent across cross-sectional units and for any member of the panel the innovation vector, $w_{it} = (u_{it}, \varepsilon'_{it})'$, satisfies some regular conditions such that, as shown by Kao and Chiang (2000), the long-run covariance matrix of $\{w_{it}\}$ is given by :

$$\Omega = \Sigma + \Gamma + \Gamma', \tag{11}$$

with

$$\Omega = \sum_{j=-\infty}^{\infty} E\left(w_{ij} w_{i0}'\right) = \left[\begin{array}{cc} \Omega_u & \Omega_{u\varepsilon} \\ \Omega_{\varepsilon u} & \Omega_{\varepsilon} \end{array} \right],$$

$$\Gamma = \sum_{j=1}^{\infty} E\left(w_{ij} w_{i0}'\right) = \left[\begin{array}{cc} \Gamma_u & \Gamma_{u\varepsilon} \\ \Gamma_{\varepsilon u} & \Gamma_{\varepsilon} \end{array} \right],$$

$$\Sigma = E\left(w_{i0} w_{i0}'\right) = \left[\begin{array}{cc} \Sigma_u & \Sigma_{u\varepsilon} \\ \Sigma_{\varepsilon u} & \Sigma_{\varepsilon} \end{array} \right],$$

and the one-sided long run covariance by:

$$(12) \qquad \Delta = \Sigma + \Gamma,$$

with

$$(13) \qquad \Delta = \sum_{j=0}^{\infty} E\left(w_{ij} w_{i0}'\right) = \left[\begin{array}{cc} \Delta_u & \Delta_{u\varepsilon} \\ \Delta_{\varepsilon u} & \Delta_{\varepsilon} \end{array} \right],$$

the OLS estimator is biased, that is:

$$(14) \qquad T\left(\widehat{\beta}_{OLS} - \beta\right) \xrightarrow{p} -3\Omega_{\varepsilon}^{-1}\Omega_{\varepsilon u} + 6\Omega_{\varepsilon}^{-1}\Delta_{\varepsilon u},$$

and

$$(15) \qquad \sqrt{N}T\left(\widehat{\beta}_{OLS} - \beta\right) - \sqrt{N}\delta_{NT} \Longrightarrow N\left(0, 6\Omega_{\varepsilon}^{-1}\Omega_{u.\varepsilon}\right),$$

where

$$\Omega_{u.\varepsilon} \equiv \Omega_u - \Omega_{u\varepsilon}\Omega_{\varepsilon}^{-1}\Omega_{\varepsilon u}, \tag{16}$$

and

$$\delta_{NT} \xrightarrow{p} 6\Omega_{\varepsilon}^{-1}\left(-\frac{1}{2}\Omega_{\varepsilon u} + \Delta_{\varepsilon u}\right). \tag{17}$$

Equation (17) shows that ultimately the bias depends on the endogeneity of regressors, accounted by $\Omega_{\varepsilon u}$ term, and the serial correlation of disturbances, captured by $\Delta_{\varepsilon u}$ term.

The FMOLS estimator, therefore, corrects for these drawbacks, transforming the dependent variable and the residual properly. Defining

$$u_{it}^{+} = u_{it} - \Omega_{u\varepsilon}\Omega_{\varepsilon}^{-1}\varepsilon_{it}, \tag{18}$$

$$\widehat{u}_{it}^{+} = u_{it} - \widehat{\Omega}_{u\varepsilon}\widehat{\Omega}_{\varepsilon}^{-1}\varepsilon_{it}, \tag{19}$$

$$y_{it}^{+} = y_{it} - \Omega_{u\varepsilon}\Omega_{\varepsilon}^{-1}\Delta x_{it}, \tag{20}$$

and

$$\widehat{y}_{it}^{+} = y_{it} - \widehat{\Omega}_{u\varepsilon}\widehat{\Omega}_{\varepsilon}^{-1}\Delta x_{it}, \tag{21}$$

where $\widehat{\Omega}s$ are consistent estimates of Ωs. The endogeneity correction is achieved transforming (8) in the following way:

$$\widehat{y}_{it}^{+} = \alpha_i + x_{it}'\beta + u_{it} \; - \widehat{\Omega}_{u\varepsilon}\widehat{\Omega}_{\varepsilon}^{-1}\Delta x_{it}. \tag{22}$$

The serial correlation is swept out using the term:

$$\widehat{\Delta}_{\varepsilon u}^{+} = \widehat{\Delta}_{\varepsilon u} - \widehat{\Delta}_{\varepsilon}\widehat{\Omega}_{\varepsilon}^{-1}\widehat{\Omega}_{u\varepsilon}, \tag{23}$$

where $\widehat{\Delta}s$ are kernel estimates of Δs.

Hence the FMOLS estimator is given by:

$$\widehat{\beta}_{FM} = \left[\sum_{i,t}^{N,T}(x_{it} - \overline{x}_i)(x_{it} - \overline{x}_i)'\right]^{-1}\left[\sum_{i}^{N}\left(\sum_{t}^{T}(x_{it} - \overline{x}_i)\widehat{y}_{it}^{+} - T\widehat{\Delta}_{\varepsilon u}^{+}\right)\right], \tag{24}$$

and it converges asymptotically to:

$$\sqrt{N}T\left(\widehat{\beta}_{FM} - \beta\right) \Longrightarrow N\left(0, 2\Omega_{\varepsilon}^{-1}\Omega_{u.\varepsilon}\right). \tag{25}$$

7.2 *Estimates of the bilateral FDI positions*

Making use of the Eurostat dataset we obtain the FDI outward positions of United States, Japan and European Union in the following regions: Africa, Asia and Latin America.

Moreover, assuming that the sum of the TRIAD's FDI positions accounts for 100% of the FDI inward positions in such regions, we derive the following shares:

regions	**United States**	**Japan**	**European Union**	**Total**
Africa	0.277934	0.016493	0.705573	1.000
Asia	0.387114	0.292448	0.320438	1.000
Latin America	0.520446	0.066946	0.412608	1.000

Finally, we impose that each TRIAD's member invests in the countries belonging to these regions according to such shares and we obtain the bilateral inward FDI positions for each developing country in the panel simply applying the shares to the UNCTAD's FDI figures.

7.3 *Real business sector R&D*

Following Coe and Helpman (1995) real business sector R&D expenditures are obtained dividing the nominal expenditures by an R&D price index (PR) defined as follows:

$$PR = 0.5 * P + 0.5 * W,$$

where P stands for the implicit deflator of the business sector output, obtained by the OECD STAN dataset. Whereas W is an index of the average business sector wages (same source of P).

7.4 *Initial conditions for the R&D capital stock*

Following Griliches(1979):

$$\mathbf{R\&D}_{t_0}^{STOCK} = \frac{\mathbf{R\&D}_{t_0}^{EXPENDITURE}}{\boldsymbol{\delta} + \bar{\mathbf{g}}},$$

where δ, the depreciation rate, is equal to 0.05 and $\bar{\mathbf{g}}$ is the average annual growth rate of the business sector R&D expenditures over the period for which published R&D data are available. The $\mathbf{R\&D}_{t_0}^{EXPENDITURE}$ is the first year for which the data are available and $\mathbf{R\&D}_{t_0}^{STOCK}$ is the benchmark for the beginning of the period.

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