International Technology Diffusion and Economic Growth: Explaining the Spillover Benefits to Developing Countries

Abdoulaye Seck*
Faculté des Sciences économiques, Université Cheikh Anta Diop
Department of Economics, Suffolk University

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Abstract

Technology spillovers offer great opportunities for economic growth to developing countries that do little, if any, R&D activity. This paper explores the extent to which these countries benefit from foreign technology, the diffusion mechanisms involved, the factors that shape their absorption capabilities, and the sources of heterogeneity in the spillover gains. Results based on a non-stationary panel of 47 developing countries and covering the period 1980-2006 first indicate that the gains in terms of increased aggregate productivity are quite substantial, and the import channel appears to be more conducive to knowledge spillover than the FDI channel. In addition, developing countries that enjoy larger benefits tend to have larger stock of human capital, more openness to international trade, as well as stronger institutions. Furthermore, the results do not provide a clear answer as of the type of R&D which is assciated with more spillover benefits.

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1 Introduction

The new growth theory developed in the early 1990s suggests that innovation is a major source of technological advance, which in turn drives economic growth. This has led to the emergence of a large body of empirical research that aimed at measuring the extent to which investment in Research and Development (R&D) promotes sustained expansion of nations' production capabilities.[1] A key finding has been that these investments, which result in new

[1] Key contributions include Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992).

*Author's E-mail address: sec11208@suffolk.edu.

technologies, processes, products, and materials, benefit not only countries which perform such activities, but also foreign countries. For example, the pioneering study by Coe and Helpman (1995), focusing on developed countries, has shown that he long-run rate of return on R&D investment was 120% for the performing countries and an additional 30% for their trading partners, in terms of increased total factor productivity (TFP).

International technology spillover, which mainly occurs through import and FDI channels, offers great opportunities for economic growth to developing countries that do little, if any, R&D activity. These countries seem to be trapped into a vicious circle of insignificant R&D activity that would otherwise fuel the engine of economic growth, and the lack of significant economic progress insufficient incentives to develop a knowledge production sector. In effect, most of them have been struggling for decades to improve their economic conditions, and often times, the results have been so disappointing that some referred to them as the"economic tragedy of the XXth century" (Vila-Artadi and Sala-i-Martin, 2003). Therefore, one development strategy could consist of looking at different ways to enable these countries to benefit from international technology diffusion.

This paper sets out to explore the extent to which developing countries may gain from technology spillover, and what could explain the potential heterogeneity in their absorption capabilities. The pioneering work by Coe and Helpman (1995) has generated a fair amount of follow-up research that aimed at deepening the understanding of technology spillover. The literature has then been extended into a couple of directions (Coe et al., 2008): the measurement of foreign R&D capital stock to account for the different diffusion channels, the model specification (controlling for additional relevant factors that explain the spillover mechanism), and the econometric techniques used (panel cointegration).

Despite the large body of empirical works, little attention has been paid to developing countries. One of the few papers that focus on North-South technology spillover is Coe et al. (1997). Using a dataset of 22 developed countries as in Coe and Helpman (1995), along with 77 developing countries, the authors show that the latter can substantially benefit from the stock of knowledge developed in advanced countries. A key finding suggests that a one-percent increase in the R&D capital stock in developed countries generates a 0.06-percent increase in TFP in developing countries, the gains occurring through the import channel. The results also suggest important differences in developing countries' gains from foreign R&D: more open countries where trade is more biased towards developed countries that do more R&D are the ones that tend to gain more from technology externalities (e.g. Latin American countries vis-a-vis the US).

This paper addresses some limitations to Coe et al. (1997) in studying North-South technology spillover. Firstly, it considers both diffusion channels, e.g. imports and FDI as well. Secondly, additional sources of heterogeneity are considered, beside openness to trade and human capital, namely social and economic institutions as summarized by the World Bank ease of doing business, the index of patent protection, and the historical origin of the legal systems. Thirdly, and following Guellec and van Pottelsberghe de la Potterie (2004), different types of R&D activities are considered with respect to their sources of funds (business, government, and high education). Lastly, the paper considers more advanced econometric technique in the panel cointegration technique, namely the so-called second generation panel unit root tests and the estimation methods that outperform the regular OLS method by addressing the potential endogeneity of the regressors and the serial correlation in the error term.

A dataset of 47 developing countries and the seven most industrialized countries (G7) is considered. A panel cointegration model is developed, and the potential candidates to explaining developing countries' TFP are their foreign R&D capital stock, human capital, trade openness, inward FDI, and a set of institutional variables (ease of doing business, property rights, and the origin of the legal systems). Different interactions of the latter variables with the foreign R&D capital stock are introduced to allow for heterogeneity in the absorption of technology spillovers. To account for the different diffusion channels (imports and FDI), the foreign R&D capital stock is constructed using alternatively bilateral import and FDI shares as weights. The estimation technique is based on the Fully Modified Ordinary Least Squares.

The paper suggests the following key results. Both import and inward FDI are significant diffusion channels of technology from advanced to developing countries, and the former appears to be more conducive to technology diffusion than the latter. Also, the benefits are more substantial than the results from Coe et al. (1997) indicate. Furthermore, the differences in the gains appear to be attributable to factors such as human capital, openness to trade, and institutions.

The remainder of the paper is organized as follows. The next section introduces the empirical model. Section 3 describes the data and some key features derived from them. Section 4 presents both the test results related to the use of non stationary panel and some evidence on how developing countries gain from technology spillovers. Section 5 offers a summary and some concluding remarks.

2 Empirical Methodology

To measure the extent to which developing countries benefit from R&D activity in advanced countries, and analyze the potential sources of heterogeneity in their absorption capabilities of technology spillovers, a non-stationary panel model is considered. This technique has become very popular in analyzing issues related to the economic performance of countries in the long run and the factors that affect them. The next subsection provides some theoretical background on how foreign innovation and technology affect domestic growth or how the benefits of the R&D activities spill over onto foreign countries. Then the empirical model is presented, before some details on the panel cointegration techniques (panel unit root tests, and panel cointegration tests and estimation) are offered.

2.1 Theoretical Background

The relationship between technology and TFP is explained by the endogenous growth literature developed in the early 1990s. Helpman (2004) provides a detailed review of these theoretical innovation-driven growth models. The idea of technology spillovers refers to the benefits gained by a country from the R&D activities of its foreign partners. These gains occur mostly through international trade and FDI. International trade makes available new goods that embody foreign knowledge. One theoretical approach analyzing these spillover benefits through the import channel suggests the quality ladder assumption: Investments in new knowledge improve the quality of the existing intermediate inputs or capital goods, which then become vertically differentiated. Consequently, by importing these knowledge-embodied inputs, the economy can enjoy an increase in the aggregate productivity (TFP).

A second approach puts forth the love of variety assumption. It suggests the R&D efforts lead to an increase in the amount of horizontally differentiated inputs. By importing these newly developed goods from the R&D performing countries, a country will again be able to increase its production possibilities.

As for the FDI diffusion channel, it enables a host country to develop a contact with more technologically advanced partners. By so doing, it provides a platform for learning opportunities through which the economy gets access to more efficient production processes. One way the technology gains could occur is through the increased competition that comes with the arrival of the foreign firms. Domestic firms will then have to come up with a response strategy to the technology differential, which could be to either imitate the foreign firms' production processes, or acquire the technology-embodied inputs they use. Another way FDI can generate technology spillover is through labor turnover. Former workers in technology-advanced foreign firms bring with them their new skills and know-how to the domestic firms. In a context of relatively strong labor mobility, these gains can quickly spread to a significant part of the economy, hence benefiting to a large extent the economy as a whole in terms of increase in the aggregate productivity.

It is reasonable to expect countries to enjoy different benefits from international technology spillovers, with respect to their trade pattern, their degree of openness, and the set of domestic conditions that affect the FDI flows. To gain more from foreign technology, a country may need to import more of the goods that embody new knowledge, and this could be more likely when the trading partners invest more in R&D.

Furthermore, in order to benefit more from the FDI channel, it can be fairly assumed that an economy may have to host more foreign activities. This could be achieved for instance through an institutional framework more friendly to business activities, such as strong intellectual property rights protection, less corruption. Additionally, a more educated labor force could also provide a strong incentive to foreign investments, specially those more oriented towards high-technology activities.

2.2 Empirical Model

To analyze the extent to which domestic economies benefit from potential externalities generated by foreign investment in R&D, Coe and Helpman (1995) first suggested a simple equation relating domestic TFP to domestic R&D capital stock and foreign R&D capital stock. The latter variable is defined in such a way to account for only the import channel, e.g.

the import-share-weighted average of the domestic R&D stocks of the trading partners. As the authors mentioned, this weighting scheme does not properly reflect the level of imports. Two countries can have the same trade patterns (same technology partners, same import flows), and yet the effort to get foreign technology can be different. It is expected that the country that imports more relative to its GDP (import intensity) is likely to gain more from foreign R&D, as suggested by the growth and trade literature which suggests higher productivity as a result of more trade volumes (Grossman and Helpman, 1991). Consequently, the empirical model is extended to include an interaction between foreign R&D stock and the import ratio, a proxy for trade openness.

Model misspecification is among the empirical issues raised by the empirical literature that developed afterwards. Engelbrecht (1997) suggested human capital as a source of both productivity growth and technology spillovers. Van Pottelsberghe de la Potterie and Lichtenberg (2001) accounted for both diffusion channels, e.g. imports and FDI. Guellec and van Pottelsberghe de la Potterie (2004) raised the issue of aggregation, and suggested considering different types of R&D based on the performing sectors. Coe et al. (2008) showed that differences in institutions across countries determined to a large extent the absorption of technology spillovers.

To take advantage of all these empirical developments, the baseline specification considered in this paper is as follows.

$$\begin{aligned} \log TFP_{it} &= \alpha_i^0 + \theta_t + \alpha^M \log S_{it}^M + \alpha^F \log S_{it}^F + \alpha^H \log H_{it} \\ &\quad + \alpha^{MM} \left(m_{it} {*} \log S_{it}^M \right) + \alpha^{FF} \left(fdi_{it} {*} \log S_{it}^F \right) + \epsilon_{it}, \end{aligned} \tag{1}$$

where TFP_{it} stands for the total factor productivity of country i at time t, α_i^0 country-specific characteristics, and θ_t time-specific effects (common to all countries). S_{it}^M and S_{it}^F are foreign R&D stock available through the import channel and the FDI channel, respectively, H_{it} human capital (average years of schooling), m_{it} the ratio of total imports of goods and services to GDP, fdi_{it} the inward FDI ratio, and ϵ_{it} a white noise disturbance that captures the remaining significant influences on TFP that are not explicitly accounted for in the model. The functional form of the model (logarithmic) allows one to interpret the coefficients as elasticities, and it comes from the non linear Cobb-Douglas production function.

Foreign R&D stock is constructed as a proxy of the domestic country's stock of knowledge. It is a cumulative weighted sum of the domestic R&D capital stock of its economic partners. To account for the different diffusion channels, a common weighting scheme in the empirical literature considers the import shares or FDI shares:

$$S_{it}^M = \sum_{j=1}^{J} \psi_{ijt}^M * \frac{S_{jt}^d}{Y_{jt}} \text{ and } S_{it}^F = \sum_{j=1}^{J} \psi_{ijt}^F * \frac{S_{jt}^d}{Y_{jt}},$$

where S_{jt}^d the domestic R&D capital of developed country j, Y_{jt} its GDP, and ψ_{ijt}^M and ψ_{ijt}^F the weights, defined as follows:

$$\psi^M_{ijt} = \frac{ME_{ijt}}{M_{it}} \text{ and } \psi^F_{ijt} = \frac{FDI_{ijt}}{I_{it}},$$

with ME_{ijt} representing the imports of machinery and equipment from advanced country j, M_{it} total imports of goods and services, FDI_{ijt} the bilateral inward FDI, and I_{it} total investment.

Two remarks are in order. Firstly, this way of defining the foreign R&D stock makes the magnitude of any spillovers benefits depend upon both the performing countries and the absorbing countries. In effect, one would expect advanced countries to invest more in developing new knowledge, and the more they do, the larger would be the potential for spillover gains to their foreign partners. On the other hand, developing countries need to deploy significant efforts to the absorption of foreign technology, either by importing more of the goods that incorporate the technology, or by hosting those technologically advanced firms.

Secondly, an effort is better measured in relative terms, especially when many countries are involved in the analysis. Two advanced countries with the same stock of domestic R&D may not necessarily have devoted the same effort to the production of new technology. One needs to account for the countries resources in order to get how much of a stock of technology is obtained from one unit of resources, namely an indication of how productive the economy is in developing new knowledge. This relative approach is a more convincing way to capturing performing countries' efforts to the international technology diffusion process than the absolute approach which is dominant in the literature and which considers only the domestic stock.

Similarly, the developing countries' efforts to benefit from foreign technology need to be defined in relative terms, as it appears in the weighting scheme. In most of the cases, as in Coe et al. (1997), imports of machinery and equipment from a given advanced country are considered relative to the total import of such goods from only the R&D performing countries involved in the study, which turn the sum of the weights into unity. However, an alternative approach that could better capture developing countries' efforts would relate the imports of machinery and equipment to the total imports of the country. Supposing two countries importing the same amount of machinery and equipment from the same R&D performing countries. The traditional approach would equate the two countries as far as the foreign R&D stock is concerned. But it does not reveal any differences in the overall trade patterns of one country that seek to benefit more from technology spillover by encouraging the imports of these knowledge-embodied goods, and which would be reflected into their larger share in the total imports. The alternative approach which relates the bilateral imports of machinery and equipment to the total imports would better capture this pattern in the country's trading system. A similar idea also governs the technology spillovers gained from the FDI channel. The weight puts the countries ability to gain from foreign technology into the general perspective of its overall investment effort.

The domestic R&D capital stock in developed countries, S^d_{jt}, is constructed using the perpetual inventory method and allowing for depreciation:

$$S^d_{jt} = (1-d)S^d_{jt-1} + I^{RD}_{jt},$$

with d the depreciation rate, and I^{RD}_{jt} the R&D expenditures in country j.

Besides the total R&D spending of the economy, disaggregated R&D spending by performing sectors in developed countries are also considered: business, government, and high education. Van Pottelsberghe de la Potterie and Lichtenberg (2004) showed that the sources of funds for the R&D do matter, and they have different effects on TFP.

The model allows one to answer the questions of to what extent and why some developing may gain more than others from technology spillovers from advanced countries. $\widehat{\alpha}^M > 0$ and $\widehat{\alpha}^F > 0$ would suggest that both imports and FDI are significant diffusion channels of technology; $\widehat{\alpha}^{MM} > 0$ and $\widehat{\alpha}^{FF} > 0$ would additionally imply that countries that import more or host more foreign activities are likely to benefit more from technology spillovers.

Another contribution of the paper, as stated before, is to explore other potential sources of heterogeneity in the North-South technology spillover, in addition to what the literature has already suggested. Namely, the paper investigates whether stronger institutions are associated with more spillover benefits. The approach adopted here consists of including one additional variable at a time. Such a strategy could be problematic, for the removal of a significant variable often leads to serial correlation in the error terms in this misspecified model. Different ways to deal with this issue of inefficiency have been proposed, and the estimation strategy adopted in this paper (Fully Modified Ordinary Least Squares, explained below) directly tackles this issue, among others.

For instance, to test whether stronger protection of property rights yields additional spillover gains, the baseline model is extended in the following way:

$$\begin{aligned}\log TFP_{it} = {} & \alpha^0_i + \theta_t + \alpha^M \log S^M_{it} + \alpha^F \log S^F_{it} + \alpha^H \log H_{it} \\ & + \alpha^{MM}\left(m_{it} * \log S^M_{it}\right) + \alpha^{FF}\left(fdi_{it} * \log S^F_{it}\right) \\ & + \alpha^{MMI}\left(IPP_{it} * m_{it} * \log S^M_{it}\right) + \alpha^{FFI}\left(IPP_{it} * fdi_{it} * \log S^F_{it}\right) + \epsilon_{it}. \qquad (2)\end{aligned}$$

IPP represents the index of patent protection. In this setting, the potential role of this institutional variable in shaping countries' spillover benefits will be conditional on openness to trade and foreign investment. A significant estimate of α^{MMI} for example will suggest that the strength of the property right protection explains the differential in the gains between two developing countries with the same composition of imports, the same import intensity, and the same technology partners.

2.3 Empirical Methods

To analyze the long run effect of technology spillovers on countries' TFP, a non stationary panel regression is considered. Cointegration can be viewed as a statistical representation of a long run relationship between the variables of interest. In fact, cointegrated variables share a common stochastic trend in the long run (Stock and Watson, 1993), even if they can deviate from this equilibrium in the short run. This technique has become very popular in the literature. One of its properties is known as "super consistency" (Stock, 1987), that is as the sample size gets larger, the estimated coefficients converge faster to their true values than regular time series estimates, provided that the appropriate estimation method is applied. This makes the technique more robust to a variety of biases that often plague the estimations, like omission bias. The econometric procedure involves first testing for the panel unit root process and the existence of a cointegrating relationship, and then estimating the model.

2.3.1 Unit Root Testing

Econometric preliminaries include testing for panel unit root process and panel cointegration. Recent developments in the cointegration literature have led to what is known as the second generation panel unit root tests. By far the most commonly used test procedures are Levin, Lin, and Chu (2002, LLC henceforth), and Im, Pesaran, and Shin (2003, IPS henceforth). These tests generalize the times series ADF equation to panel data. Let y_{it} denote a variable observed across individuals $i = 1, ..., N$ and over the time period $t = 1, ..., T$, and X_{it} a set of explanatory variables. The standard ADF equation as adapted to panel data is:

$$y_{it} = \alpha_i + \delta_i t + \gamma_i y_{t-1} + \lambda_i \theta_t + X'_{it}\delta + \epsilon_{it},$$

or equivalently:

$$\Delta y_{it} = \alpha_i + \delta_i t + \rho_i y_{t-1} + \lambda_i \theta_t + X'_{it}\delta + \epsilon_{it},$$

with

$$\rho_i = \gamma_i - 1.$$

Both LLC and IPS tests assume that all series are non stationary under the null hypothesis, that is $H_0 : \rho_i = 0$ (or equivalently $\gamma_i = 1$). They differ in how they define the alternative hypothesis: while LLC imposes the same dynamics across the units ($\rho_i = \rho_j \neq 0$), the IPS procedure allows for a heterogeneity in the short run dynamics, ($\rho_i \neq \rho_j \neq 0$, for at least some units $i \neq j$). Because of these different treatments of the cross sectional units, LLC is known as a homogenous test, and IPS a heterogenous test.

Some alternative panel unit root tests have also been developed, and they deal with some limitations to the previous ones. Some drawbacks to LLC and IPS tests include common autoregressive process under the alternative (LLC), and the critical values generated under the same lag length and time period for all cross sectional units (IPS). Maddala and Wu (1999) have suggested a more general framework which extends the time series-based Fisher test. It allows for complete heterogeneity in the data generating process under the alternative of stationary process, and does not involve simulating the adjustment factors due to the sample size and the specification. Another test procedure is Hadri (2000): unlike the previous tests, this Lagrange Multiplier (LM) test assumes under the null hypothesis that all series are stationary. It allows for heterogeneity or serial correlation in the error terms, as well as homogeneity.

2.3.2 Cointegration Testing

If the data generating process of the variables turns out to be a panel unit root, then the next step is testing for panel cointegration. If the variables have a long run relationship, then the residuals from the estimation of this relationship have to be stationary. Running a regression based on non-cointegrating relationships leads to spurious estimation. In such a case, the correlation generated by the regression are due to other variables (confounding or lurking variables) that influence those in the model, instead of a real causal relationship. Various panel cointegration tests have been suggested, and they are based on their time series counterparts. Pedroni (1999, 2004), Kao (1999), and Larson et al. (2001) extended the Engle and Granger (1987) time series framework to panel data. They are residual-based tests. The general test procedure starts with the following regression equation between, say, variables y_{it} and X_{it}:

$$y_{it} = \alpha_i + \delta_i t + X_{it}\beta + \varepsilon_{it}.$$

Under the null hypothesis of no cointegration, the residuals $\widehat{\varepsilon}_{it}$ contain a unit root, that is non stationary. The second step then consists of testing for panel unit root on the residuals, by running the following ADF regression:

$$\Delta\widehat{\varepsilon}_{it} = \rho_i \widehat{\varepsilon}_{it-1} + \sum_{k=1}^{K} \psi_k \Delta\widehat{\varepsilon}_{it-k} + \nu_{it}.$$

The null hypothesis of no cointegration means that $\rho_i = 0$, that is the residuals have panel unit root. Comparison between the panel cointegration tests is often based on the time length of the data. For example, Gutierrez (2003) has demonstrated that, in the case of small (high) time dimension, Kao test has higher (lower) power than the Pedroni test, and both tests show higher power than the Larson et al. test. In addition, while the Pedroni tests can only be applied to a number of series not greater than six, the Kao test is more general. It also assumes individual specific intercept terms and homogenous coefficients in the first stage. Under the null of no cointegration, the test statistic is shown to converge asymptotically to the standard normal distribution. Results from both panel unit root and cointegration tests will determine the variables to be considered in the model, that is the cointegrating relationship.

2.3.3 Estimation via Panel Cointegration

When developing an estimator for a panel cointegration model, two issues generally arise: a potential endogeneity of the regressors, and a heterogeneity of the variance-covariance matrix (e.g. serial correlation). As a consequence, the regular OLS method tends to generate biased coefficient estimates, and the standard test statistics (e.g. t-statistics or F-statistic) become irrelevant. One of the estimators that have been suggested as an alternative is known as the Fully Modified Ordinary Least Squares (FMOLS). It was first developed, as it is often the case, in the times series context. Pedroni (1996) first generalized it to panel data framework.[2] The central theme of the FMOLS estimation strategy was to "pool only the information concerning the long run relationship", and "allow the short run dynamics to be potentially heterogenous." Three versions of this estimator have been developed: residual-FM, adjusted-FM, and group-FM. While the first two pool the data along the within dimension, the latter does so along the between dimension. Based on their performance in finite samples, Pedroni (2000) has shown that the group-FMOLS has more desirable properties, and it is associated with lower size distortion. Phillips and Moon (1999) have proposed a version which asymptotic properties are derived from joint limits, in contrast to the previous estimators that are based on sequential limits.

The basic specification that is considered by the FMOLS estimator (Phillips and Moon's version) is as follows:

$$\begin{aligned} y_{it} &= \alpha_i + \delta_i t + \theta_t + X_{it}^{'}\beta + \varepsilon_{it}, \\ X_{it} &= X_{it-1} + \mu_{it}. \end{aligned} \tag{3}$$

In constructing the estimator, the first step consists of taking the deviation about the mean of both dependent and independent variables: $\widetilde{y}_{it} = y_{it} - \overline{y}_i$ and $\widetilde{X}_{it} = X_{it} - \overline{X}_i$.

Next, the model is estimated with the Least Squares Dummy Variable method, and the corresponding residuals are used to estimate the long-run variance-covariance matrices of the errors terms, namely $\widehat{\Omega}_\mu$ and $\widehat{\Omega}_{\varepsilon\mu}$. The following expression of the dependent variable is then considered:

$$\widetilde{y}_{it}^{*} = \widetilde{y}_{it} - \widehat{\Omega}_{\varepsilon\mu}\widehat{\Omega}_{\mu}^{-1}\Delta\widetilde{X}_{it}.$$

Finally the between-dimension, group mean panel FMOLS estimator is computed as follows:

$$\widehat{\beta}_{FMOLS} = \left(\sum_{i=1}^{N}\sum_{t=1}^{T}\widetilde{X}_{it}\widetilde{X}_{it}^{\prime}\right)^{-1}\left(\sum_{i=1}^{N}\sum_{t=1}^{T}\widetilde{X}_{it}\widetilde{y}_{it}^{*} - T\sum_{i=1}^{N}\widehat{\lambda}_i\right), \tag{4}$$

with

$$\widehat{\lambda}_i = \widehat{\Gamma}_{\varepsilon\mu i} + \widehat{\Omega}_{\varepsilon\mu i}^{0} - \frac{\widehat{\Omega}_{\varepsilon\mu i}}{\widehat{\Omega}_{\mu i}}\left(\widehat{\Gamma}_{\mu i} + \widehat{\Omega}_{\mu i}^{0}\right),$$

where $\widehat{\Gamma}$ and $\widehat{\Omega}^0$ are derived from the decomposition of the long-run variance-covariance matrix $\widehat{\Omega}$, and the latter is the contemporaneous covariance, the former the weighted sum of the autocovariances.

[2] The time series counterpart was proposed by Phillips and Hansen (1990) as a way to deal with the same issues of inefficiency and inconsistency. The former is brought about by the serial correlation, while the latter is a consequence of the endogeneity.

This estimator has been opposed in the econometric literature to the Dynamic OLS (DOLS) estimator.[3] While FMOLS uses a non-parametric technique, the DOLS estimator is essentially a parametric approach, and the model specification basically adds lags and leads of the independent variables. Furthermore, Kao and Chiang (1999) suggests that both FMOLS and DOLS estimators have the same limiting distribution, but they have different performance in finite samples. The DOLS estimator appears to improve the properties of the simple OLS more than the FMOLS does. But a main drawback is its higher sensitivity to the leads and lags of the regressors. More importantly, in a panel setting with relatively small time dimension and many regressors, a large number of lags and leads can simply make the regression impossible. In that sense, the use of the DOLS estimator appears to be more conditional on the data length.

3 Data and Variables

The data collected cover 47 developing countries: 19 from Africa, 13 from Latin America, and 15 from Asia and the Pacific regions. The developed countries selected are the G7 countries. One reason why these seven advanced economies are chosen is that they account for a large part in the world R&D activity. Among the 21 OECD countries that the literature often uses to study spillovers within the developed world, the G7 countries accounted for about 70 percent of total R&D expenditures in 2004.[4] Another reason resides in their broader economic ties with a larger range of developing countries. This ensures more availability of data for developing countries, specially with respect to bilateral imports and FDI, and foreign R&D capital stock. The period covered stretches from 1980 to 2006.

The TFP variable is calculated using the common approach known as the development or growth accounting method. It assumes a functional form for the production function (e.g. Cobb-Douglas), and then computes the TFP as a residual:

$$\log TFP_{it} = \log Y_{it} - \alpha \log K_{it} - (1-\alpha)\log L_{it}. \tag{5}$$

Y_{it} represents real GDP of developing country i in year t, K_{it} the physical capital stock, L_{it} the labor force, α the capital income share in GDP (set to one third). The capital stock is obtained through the perpetual inventory method:

$$K_{it} = (1-\delta)K_{it-1} + I_{it}.$$

δ is the depreciation rate (set to .10), I_{it} the real gross fixed capital formation.

Human capital is measured as the average years of schooling of people over 25 years old. Barro and Lee (2000) provided quinquennial statistical information on schooling for many countries up to 2000. Interpolation is used to fill in both the years in between each 5-year

[3] The DOLS estimator was first adapted to panel data setting by Kao and Chiang (1997). Mark and Sul (1999) later proposed a refined variation which is a weighted estimator, while the first is an unweighted one, and it has been shown to perform better in small samples.

[4] Own calculation from OECD data.

segment and to forecast for the most recent years. This interpolation assumes constant rate of growth over a given subperiod, and the rate in the 1995-2000 period is used for the post-2000 years.

Institutional variables include the ease of doing business, the index of patent protection, and the historical origin of the legal systems. The World Bank index that summarizes the ease of doing business includes a large variety of factors that could possibly influence the economic decisions along with the performance of both domestic and foreign firms, with actual or potential ties with the economy. Launched in 2003, the index is a comprehensive measure of a wide range of juridictions that tell about government regulations. It covers among others trade across borders, protection of investors, registration of properties. The updated index of patent protection by Park (2008) offers a measure of the strength of intellectual property rights. For the origin of the legal systems, 95 percent of the countries in the sample have either the British or the French system. So the variable will allow a comparison between the British common law and the French civil law. Except for the index of patent protection, the other two variables are time invariant. For the ease of doing business, the ranking in 2006 is considered.

Tables 1 and 2 provide some descriptive statistics. While the first summarizes the evolution and structure of the domestic R&D stock of the seven developed countries, the latter describes the data for the 47 developing countries.

Over the period 1980-2006, advanced countries have been investing a significant amount in the production of new knowledge. For countries like Canada, Italy, Japan, and the US, total spendings on R&D have more than tripled. In most of the countries, this effort in the production of knowledge is so important that this increase in the domestic R&D capital has outpaced the increase in the physical capital (in all countries except France). Furthermore, the business sector accounts for more than two-third of the investment effort. In countries like Japan and the US, business R&D represents more than 70 percent of the total investment. In addition, the business and high education sectors are the ones that have enjoyed the highest increased over the period.

These features of the R&D activities in developed countries may have some implications in terms of the magnitude of the spillover gains. It could be more beneficial to strengthen the economic ties (e.g. trade and FDI) with countries that devote more effort in the development of new technology. Because most of the R&D expenditure is performed by the business sector, it could be more rewarding to find ways to attract those firms that are involved in the production of new knowledge.

Table 1. Domestic R&D capital stock of the G7 countries: evolution and structure.

	Business		Government		High Education		All Sectors	
	S^d_{06}/S^d_{80}	$Share$	S^d_{06}/S^d_{80}	$Share$	S^d_{06}/S^d_{80}	$Share$	S^d_{06}/S^d_{80}	$Share$
Canada	4.76	55.19	1.83	14.07	1.40	30.39	4.00	100.00
France	2.93	61.66	2.74	19.61	2.48	17.55	2.82	100.00
Germany	2.48	68.65	2.07	14.10	1.66	17.42	2.27	100.00
Italy	3.14	52.00	1.98	20.98	5.88	26.60	3.26	100.00
Japan	5.45	70.35	1.95	9.70	1.94	17.23	3.98	100.00
U.K.	1.65	63.01	0.48	23.11	2.57	18.67	1.44	100.00
U.S.	3.27	70.63	1.75	13.99	4.01	12.09	3.05	100.00
Sample	3.57	68.11	1.84	14.28	3.10	15.63	3.09	100.00

Notes: The evolution is measured by the ratio of the value in 2006 to the value in 1980. The structure is given by the percentage share in the total R&D for each sector in a given country for the year 2006. A fourth sector (Private Non-Profit Organizations) is not considered due to lack of data. Therefore, the values for the three sectors do not add up to the total for "All Sectors" (Source: OECD).

In Table 2, the descriptive statistics show, for each variable, the average across each of the three regions, as well as the figures for the whole sample. Overall, the foreign technology stock has increased across the different regions, which is an indication of the combined effort by developed countries to invest more in technology and by developing countries to open up their economies to international trade and foreign activities. In addition, the increase in the foreign stock is more pronounced through the FDI channel, with a factor of almost three, against less than two for the import channel.

African countries appear to have gained less in terms of increase in foreign R&D stock, and this has gone hand in hand with a lower performance in terms of economic growth, with an increase in TFP by less than two percent, most of which occurring after the mid-1990s. The largest improvement in human capital and in the protection of property rights have less to do with real social or economic achievement than the lower starting points of the countries. In such a situation, small increases tend to be magnified in terms of larger rates of growth.

Latin American countries appear to have enjoyed the largest increase in their foreign R&D capital, both through the FDI and the import channel (by factors of 3.14 and 2.46, respectively). Their import ratio has increased by 73 percent over the period, and most importantly, their FDI stock has increased by a factor of more than 23, which is an increase by almost 2300 percent. This could also reflect their technology proximity to the center of the world technology, namely the US, both in terms of dynamism and level. In effect, its total R&D investment effort in 2006 was larger than the combined effort of the other advanced countries (3.8 percent higher), and it accounts for nearly half of the G7 countries' R&D stock (precisely 48 percent), from only about 14 percent in the early 1980s.

As for Asian and Pacific countries, their quite remarkable economic performance (62-percent increase in TFP on average) has been accompanied with significant effort to improve the quality of the institutions. The strength of the property rights' protection has increased significantly, which has contributed to a good ranking according to the World Bank ease of doing business (more than 70 percent of the developing countries in the top half are from that region). Additionally, more than half have the British common law legacy, which is generally viewed as more oriented towards better market outcomes than the French civil law.

Table 2: Summary statistics for developing countries, by regions.

		Africa	Latin America	Asia-Pacific	Sample
TFP		1.02	1.06	1.62	1.23
S^M	Business	1.30	2.78	1.70	1.95
	Government	0.97	1.98	1.24	1.41
	High education	1.18	1.98	1.12	1.42
	All sectors	1.20	2.46	1.50	1.73
S^F	Business	2.79	3.55	3.35	3.27
	Government	1.63	1.87	2.05	1.87
	High education	3.07	2.84	3.02	2.98
	All sectors	2.61	3.14	3.03	2.95
Human capital		2.59	1.37	1.19	1.81
Import ratio		1.49	1.73	2.18	1.78
FDI stock ratio		9.00	23.16	7.14	12.32
IPP		1.80	1.25	1.64	1.57
EDB		26.32	53.85	73.33	100.00
LEGALBR		42.11	0.00	53.33	100.00
Count		19	13	15	47

Notes: Equal weights are considered when computing the averages; S^M represents foreign R&D stock that emphasizes the import channel, and S^F (inward) FDI channel. Figures represent ratio of value in 2006 to value in 1980, except for EDB and $LEGALBR$ that show, respectively, the percentage of countries within the region that are highly ranked according to the index of the ease of doing business (top half), and countries with the British legal origin.

These stylized facts suggest some hypotheses about some of the explanations of why some developing countries may have benefited more than others from technology spillovers. Firstly, one may expect the effect of foreign technology on domestic TFP to differ with respect to the channels. Additionally, given the sectorial structure of the R&D activity within the developed countries, developing countries may benefit more from the business R&D. Furthermore, more open countries can be expected to gain more, especially from the import channel. While countries with larger human capital and much easier framework for business activities may benefit more through both channels, countries with stronger patent protection could mainly benefit through the FDI channel.

4 Results

Table 3 provides the results of different panel unit root tests: the homogenous Levin, Lin, and Chu (2002) test, the heterogenous Im, Pesaran, and Shin (2003) test, the more general Hadri (2000) LM test with its three specifications, and the heterogenous Maddala and Wu (1999) Fisher-based test. Except for the Hadri test, the null hypothesis assumes panel unit root process. Therefore an insignificant test statistic means a failure to reject the null of panel unit root (the opposite for the Hadri test which assumes stationarity under the null hypothesis).

Table 3: Panel unit root test results.#

	LLC	IPS	Hadri			MW
			Homo	Hetero	SerDep	
$\log TFP$	-0.55	-2.15	90.27***	65.84***	9.81***	109.73
	(0.29)	(0.30)	(0.00)	(0.00)	(0.00)	(0.13)
$\log S^M\_Business$	2.31	-1.08	101.58***	100.50***	11.68***	118.94**
	(0.99)	(0.13)	(0.00)	(0.00)	(0.00)	(0.04)
$\log S^M\_Government$	2.30	-1.20	98.11***	96.47***	11.56***	106.49
	(0.98)	(0.11)	(0.00)	(0.00)	(0.00)	(0.17)
$\log S^M\_H.Educ.$	2.44	-1.05	102.55***	99.99***	11.70***	94.37
	(0.99)	(0.14)	(0.00)	(0.00)	(0.00)	(0.47)
$\log S^M\_AllSectors$	2.31	-1.08	101.78***	100.68***	11.68***	112.08*
	(0.99)	(0.13)	(0.00)	(0.00)	(0.00)	(0.09)
$\log S^F\_Business$	26.87	-3.67	97.08***	99.19***	11.57***	69.35
	(1.00)	(1.00)	(0.00)	(0.00)	(0.00)	(0.97)
$\log S^F\_Government$	32.09	-3.95***	88.87***	93.82***	10.81***	106.27
	(1.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.18)
$\log S^F\_H.Educ.$	9.99	-0.27	100.14***	103.72***	11.38***	58.52
	(1.00)	(0.39)	(0.00)	(0.00)	(0.00)	(0.99)
$\log S^F\_AllSectors$	26.78	-1.97**	96.62***	99.31***	11.49***	77.51
	(1.00)	(0.02)	(0.00)	(0.00)	(0.00)	(0.89)
$\log H$	-13.20***	-1.58*	108.20***	106.70***	27.20***	200.70***
	(0.00)	(0.05)	(0.00)	(0.00)	(0.00)	(0.00)

Notes: Column LLC reports the Levin, Lin, and Chu (2002) t-star statistic; IPS the Im, Pesaran, and Shin (2003) the weighted t-bar; Hadri the Hadri (2000) z(mu) statistic from different scenarios of the ADF regression: homoskedastic disturbances across the units (homo), heteroskedastic disturbances across the units (hetero), and controlling for the serial dependence in the error terms (serial); and MW the Maddala and Wu (1999) chi square statistics. The p-values are in parentheses under the test statistics, and the level of significance for these one tailed-tests is indicated by * (10%), ** (5%), and *** (1%). An insignificant test statistic means a failure to reject the null hypothesis of panel unit root, except for the Hadri tests that assume stationary process under the null.

#All the interaction variables considered in the different specifications also show a panel unit root.

As the results show, for most variables, all tests unequivocally lead to the conclusion of panel unit root. Where some conflicting results do exist, at least more than half of the test procedures do fail to reject the null of panel unit root process. The next step then consists of testing for panel cointegration; that is identifying any possible long run relationship between these non stationary variables.

Tables 4 to 8 contain the results of the Pedroni and Kao tests for panel cointegration, along with the estimated cointegrating relationships. In Table 4, estimation results for the baseline model (equation 1) are shown. Table 5 explores whether human capital constitutes a potential source of heterogeneity in the benefits from technology spillovers, provided a given level of openness and FDI. Tables 6, 7, and 8 investigate the role of institutions: the ease of doing business, the strength of the property right protection, and the historical origin of the legal systems, respectively.

The cointegration tests broadly reject the null hypothesis of no cointegration. Conflicting results do exist between the seven test statistics of the Pedroni tests and the Kao ADF test for the baseline model in Table 4. But in most of the cases, more than half of the tests point to the same favorable conclusion that the series do share a common trend in the long run.

4.1 Technology Spillover: The baseline estimation

The results of the baseline model in Table 4 first indicate that the spillover gains are quite substantial. The import channel is associated with an (unconditional) elasticity of more than 0.16, meaning that a one percent increase in a developing country's foreign R&D stock is translated into more than 0.16 percent increase in its aggregate productivity. In addition, the more the country is open to international trade, the more it gains. In effect, a one percentage point increase in the import ratio brings a marginal spillover benefit of more than 0.11 percent (conditional elasticity). These gains are more substantial than those found in Coe et al. (1997). The authors found no direct gains through the import channel, all of the benefits are conditional upon some openness to trade. And even these conditional gains are much smaller than those found here (about half). On the other hand, the combined direct and indirect gains are close in magnitude to those in Coe and Helpman (1995) for OECD countries (0.30).

As for the FDI channel, the results indicate that the spillover gains are determined by the extent of the foreign activities hosted by a developing country. The insignificant coefficient on the foreign R&D stock is an indication of no (significant) direct gains. The interaction term that involves foreign R&D capital stock and inward FDI shows a substantial gain: an increase in the stock of FDI relative to GDP is associated with a marginal spillover benefit of more than 0.15.

When it comes to the types of R&D, the results indicate some heterogeneity. As for the direct gain through both channel, the government-funded R&D generates more spillovers. The negative coefficients associated with the high education R&D are more of a statistical discrepancy than a theoretically-grounded phenomenon. When the gains conditional on openness to trade and foreign investment are considered however, the other sectors tend to play an equally or more important role in the spillover mechanism. Therefore, based on these results, one cannot clearly tell what type of R&D is definitely associated with more spillover gains. This is in contrast with Guellec and van Pottelsberghe de la Potterie (2004) who indicate that the business R&D is the leading activity as far as technology spillover is concerned. Their result is however based on advanced countries, where the strong interrelations between the business firms as well as the leading role of the sector in the overall R&D effort can help explain this finding. However, when the North-South technology diffusion is considered, the leading role of the business sector is less pronounced to the point that the other sectors can play an equally important role.

Another key determinant of TFP is human capital. In all sets of estimations, countries with more educated labor force gain directly in terms of stronger economic performance. This finding is consistent with some approaches that treat human capital as an explicit argument in the production function, and others that consider increase in human capital as an innovation that occurs outside the R&D sector, as in Englebrecht (1997).

Table 4: Estimation results of the baseline model.

	All Sectors	Business	Government	H.Edu.
$Intercept$	-0.0130	-0.0117	-0.0196	828.4387
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^M$	0.1658***	0.1648***	0.1724***	-0.4963***
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^F$	0.0404	0.0474*	0.0758*	-0.5004***
	(0.20)	(0.09)	(0.09)	(0.00)
$\log H$	0.0133**	0.0139*	0.0078	0.2062***
	(0.01)	(0.09)	(0.35)	(0.00)
$\log S^M * m$	0.1143***	0.1146***	0.1385***	0.7913***
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^F * fdi$	0.1524***	0.1369***	0.0761	0.0844***
	(0.00)	(0.00)	(0.13)	(0.00)
F-stat	159.06	162.48	126.92	11218.61
p-value(F-stat)	(0.00)	(0.00)	(0.00)	(0.00)
Panel v-Statistic	0.05	2.10**	-1.76*	-1.27
Panel rho-Statistic	4.46***	4.16***	4.79**	6.76***
Panel PP-Statistic	1.13	-1.97*	0.76	6.70***
Panel ADF-Statistic	1.02	-3.96***	-2.99***	6.07***
Group rho-Statistic	5.93***	5.66***	6.11***	8.00***
Group PP-Statistic	-2.30***	-4.92***	-0.44	3.66***
Group ADF-Statistic	-2.17**	-6.69***	-2.73**	2.99***
Kao ADF t-stat	-1.63*	-1.46*	-0.49	0.43

Notes: The dependent variable is $\log TFP$. The significance at 10, 5, and 1% are indicated by *, **, and ***. The p-values are in parentheses. For the cointegration tests, an insignificant test statistic means a rejection of the null hypothesis of no cointegration.

4.2 Technology Spillover: Role of human capital

The results in Table 5 suggest that investment in human capital has a direct effect on TFP, but also an indirect effect through foreign technology absorption. The indirect effect of human capital appears to be much stronger than the direct effect. In effect, the coefficient on the average years of schooling (in logs) suggest that a one percent increase in the number of years of schooling of the average worker age at least 25 is translated into an increase in TFP by less than 0.01 percent, on average. On the other hand, from the same degree of openness to trade and the same FDI, a country that adds one more year to its average school attainment gets a differential in the foreign technology gain of almost 0.11-percentage point increase in TFP through the import channel, and more than half a percentage point through the FDI channel. This result contrasts with Coe et al. (1997) who find that education has no significant effect on spillovers, despite the identical way of proxing human capital, e.g. average years of schooling. This could be attributable to the sample differences (time period, and countries involved), or simply the model specification or the estimation strategies (omission variables, e.g. FDI channel).

Table 5: Estimation results with the role of human capital.

	All Sectors	Business	Government	H.Edu.
$Intercept$	-0.0135	-0.0120	-0.0211	-0.0155
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^M$	0.2674***	0.2630***	0.2452***	0.2573***
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^F$	0.2038***	0.2001***	0.3535***	-0.1458***
	(0.00)	(0.00)	(0.00)	(0.00)
$\log H$	0.0079**	0.0086**	0.0049	0.0159*
	(0.03)	(0.03)	(0.55)	(0.06)
$\log S^M * m$	0.1643***	0.1637***	0.1696***	0.1658***
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^F * fdi$	0.0989**	0.0869**	-0.0197	0.1545***
	(0.02)	(0.03)	(0.69)	(0.00)
$\log S^M * m * H$	0.1088***	0.1050***	0.0562***	0.1165***
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^F * fdi * H$	0.5806***	0.5350***	1.0325***	0.4918***
	(0.00)	(0.00)	(0.00)	(0.00)
F-stat	213.75	218.11	188.88	166.77
p-value(F-stat)	(0.00)	(0.00)	(0.00)	(0.00)
Kao ADF t-stat	-2.15**	-3.59***	-1.04	-0.71

Notes: The dependent variable is $\log TFP$. The significance at 10, 5, and 1% are indicated by *, **, and ***. The p-values are in parentheses.

An alternative and more interesting proxy of human capital, still focusing on education attainment, would also consider the quality of the educational systems. Coe et al. (2008)

follow such a strategy in the context of developed countries, and show that human capital is indeed associated with some technology spillover effects. This kind of statistical information, when available for developing countries, would be more descriptive of the direct and indirect effect of human capital on the aggregate productivity.

The failure to reject the null hypothesis of no cointegration does in some cases not allow to compare between the different types of R&D. Only the variables included in the "All Sectors" model and the "Business" model show a cointegrating relationship.

Overall, investment in human capital is associated with significant spillover effects. This is line with the view of investment in human capital as innovation that occurs outside the R&D sectors (Englebrecht, 1997). On average, these indirect effects of education on TFP appears to dominate the direct effects, provided some level of openness to both trade and foreign investments.

4.3 Technology Spillover: Role of institutions

Three indicators of the quality of the institutions are considered: the ease of doing business, the index of patent protection, and the historical origin of the legal system. Although they may not be viewed as totally separate, considering one at a time allows one to capture either the overall quality (ease of doing business), or to single out one aspect of the institutional framework which is of vital interest to technology diffusion (patent protection), or simply to analyze how the actual, broad social and economic institutions are shaped by the historical legacy.

4.3.1 Ease of doing business

Table 6 considers the first institutional variable; that is the ease of doing business. The way this variable is constructed (single year dummy) does not allow one to test any potential direct effect on aggregate productivity within this panel setting. Instead, the conditional effect is considered, and it allows to compare the absorption of technology spillovers by two developing countries with the same level of openness to trade and foreign investments. Results clearly indicate that a developing country that provides a more friendly institutional environment is also the one that benefits the most from technology spillovers. The spillover gains appear to be much stronger through the FDI channel than the import channel.

This result is similar to that found for advanced countries, as in Coe et al. (2008). But since the authors do not account explicitly for the other channel , e.g. FDI, one may not conclude that the magnitude of the effect of this institutional variable is the same for both developed and developing countries. We could reasonably expect a larger payoff to a developing country from an improvement of its overall institutions. The developing world is characterized both by the lower quality of and larger heterogeneity in the institutional setting. While the G7 countries and other OECD members generally have a high ranking according to the different institutional criteria accounted for by the index, and tend to form a more homogenous group, the developing countries on the other hand are more disperse along the scale, and with a very few exception (Singapore ranking number 1), most of them are in the bottom half. This suggests some significant potentials for substantial gains associated with an improvement in the institutional framework, which would be reflected by a relatively smaller effect for advanced countries. One may then hypothesize that augmenting the Coe et al. (2008) by accounting directly for the FDI channel would generate such a lower effect.

Furthermore, all types of technology sources appear to be associated with significant spillover effects due to the ease of doing business. A sound institutional environment provides among others good protection to investors, trade policies across borders, or contract enforcements, all of which that are different forms of incentives that enable developing countries to develop some ties with the foreign firms, government, or high education. Such ties will ultimately lead to technology spillovers either through more trade, or through more foreign activities in the domestic economy.

Table 6: Estimation results with the ease of doing business.

	All Sectors	Business	Government	H.Edu.
$Intercept$	-0.0122	-0.0113	-0.0188	-0.0146
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^M$	0.1970***	0.1943***	0.2322***	0.2108***
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^F$	0.0536	0.0471	0.0211	0.0256
	(0.13)	(0.14)	(0.69)	(0.47)
$\log H$	0.0156*	0.0163**	0.0082	0.0182**
	(0.05)	(0.04)	(0.32)	(0.02)
$\log S^M * m$	0.1216***	0.1186***	0.1642***	0.1321***
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^F * fdi$	0.0934**	0.0878**	0.0329	0.1089**
	(0.03)	(0.02)	(0.51)	(0.01)
$\log S^M * m * EDB$	0.0491**	0.0492**	0.0811***	0.0562
	(0.01)	(0.01)	(0.00)	(0.66)
$\log S^F * fdi * EDB$	0.2376***	0.2219***	0.2589***	0.1609***
	(0.00)	(0.00)	(0.00)	(0.00)
F-stat	207.24	214.21	163.99	166.48
p-value(F-stat)	(0.00)	(0.00)	(0.00)	(0.00)
Kao ADF t-stat	2.68***	-2.52**	-3.17***	3.42***

Notes: The dependent variable is $\log TFP$. EDB is a dummy variable that take the value of 1 if the country if the country is ranked in the top half in 2006, and 0 otherwise. The significance at 10, 5, and 1% are indicated by *, **, and ***. The p-values are in parentheses.

4.3.2 Property rights protection

Table 7 considers another institutional variable: the index of patent protection. Overall, countries with stronger protection of the intellectual property rights appear to significantly benefit more than others from technology spillovers. Most of gains occur through the import channel, the gains through the FDI channel being insignificant, on average.

As far as the FDI channel is concerned, the results could suggest that the protection scheme offered is not sufficiently strong for the developing countries to gain from foreign technology. In the context of advanced countries where property right protection is strong enough, this variable has been shown to bring significant differences across countries when it comes to technology diffusion (Coe et al., 2008).

Additionally, when compared with the spillover gains associated with the ease of doing business, the smaller gains associated with the patent protection would further suggest that the effort to get the most out of any improvement in the institutional setting should focus on all of its aspects, for they are more likely to be complementary to one another. Improving the protection to investors would not generate any significant benefits to the economy when at the same time the contract enforcements or the policies regarding trading across borders are worsening. This view of institutions as a collection of strongly complementary and reinforcing policies can help explain why any of these policies, when isolated, may lead to smaller or even insignificant economic benefits.

Table 7: Estimation results with the index of patent protection.

	All Sectors	Business	Government	H.Edu.
$Intercept$	-0.0142	-0.0129	-0.0201	-0.0176
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^M$	0.0944**	0.0935**	0.1094***	0.0877**
	(0.01)	(0.01)	(0.00)	(0.02)
$\log S^F$	-0.0491	0.0365	0.0604	-0.1028
	(0.49)	(0.57)	(0.59)	(0.14)
$\log H$	0.0120	0.0126	0.0092	0.0129
	(0.15)	(0.13)	(0.28)	(0.13)
$\log S^M * m$	0.1237***	0.1242***	0.1509***	0.1224***
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^F * fdi$	0.1059**	0.0929**	0.0762	0.1179***
	(0.03)	(0.03)	(0.15)	(0.01)
$\log S^M * m * IPP$	0.0464**	0.0463**	0.0406**	0.0510**
	(0.02)	(0.02)	(0.04)	(0.01)
$\log S^F * fdi * IPP$	0.0710	0.0668*	0.0118	0.0884**
	(0.11)	(0.09)	(0.86)	(0.04)
F-stat	169.27	173.10	132.38	141.88
p-value(F-stat)	(0.00)	(0.00)	(0.00)	(0.00)
Kao ADF t-stat	-2.06**	-4.47***	-1.63**	-1.52*

Notes: The dependent variable is $\log TFP$. IPP is the index of patent protection, ranging form 0 to 10, higher values meaning a strengthening of the protection of intellectual property rights. The significance at 10, 5, and 1% are indicated by *, **, and ***. The p-values are in parentheses.

4.3.3 Legal systems

Table 8 explores the potential role of the historical origin of the legal systems in explaining the heterogeneity in the absorption capabilities of technology spillovers by developing countries. The way the legal origin variable enters the model (dummy that takes the value of 1 if British origin), and the fact that most of the countries are either of British or French systems, allow one to compare between these two historical legacies, which also turn out to represent the most distinct approaches to laws and regulations. As the results clearly indicate, on average, countries with the British legal origin appear to benefit from technology spillover through the FDI channel, while countries with the French legal system benefit from the import channel. Broadly, the marginal spillover gains generated by the British legal system through the FDI channel is 0.07-percentage point increase in aggregate productivity, while those associated with the French legal system through the import channel are 0.11-percentage point, again provided the same level of openness to trade and foreign investment.

Table 8: Estimation results with the legal origins.

	All Sectors	Business	Government	H.Educ.
Intercept	-0.0127	-0.0116	-0.0182	-0.0153
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^M$	0.2572***	0.2551***	0.2747***	0.2656***
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^F$	0.0278**	0.0149*	0.0175*	-0.0164*
	(0.04)	(0.06)	(0.07)	(0.06)
$\log H$	0.0099	0.0104	0.0030	0.0118**
	(0.24)	(0.21)	(0.71)	(0.01)
$\log S^M * m$	0.1457***	0.1449***	0.1706***	0.1467***
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^F * fdi$	0.1609***	0.1449***	0.0472	0.1875***
	(0.00)	(0.00)	(0.36)	(0.00)
$\log S^M * m * LEGALBR$	-0.1101***	-0.1086***	-0.1237***	-0.1232***
	(0.00)	(0.00)	(0.00)	(0.00)
$\log S^F * fdi * LEGALBR$	0.0697**	0.0651**	0.1667**	-0.0025*
	(0.01)	(0.01)	(0.01)	(0.09)
F-stat	197.89	200.70	177.76	173.71
p-value(F-stat)	(0.00)	(0.00)	(0.00)	(0.00)
Kao ADF t-stat	-2.90***	-4.23***	-0.81	-0.64

Notes: The dependent variable is $\log TFP$. $LEGALBR$ is a dummy variable that takes the value of 1 if the country's historical legacy is British, and 0 otherwise. The significance at 10, 5, and 1% are indicated by *, **, and ***. The p-values are in parentheses.

The empirical evidence all too often point to the superiority of the laws of common law countries (originating in British law) over the laws of civil law (originating in Roman law) and particularly French civil law countries. The Legal Origins Theory, when opposing the legal families, describes the French civil law as associated with a “heavier hand of government ownership and regulation” than the British common law, therefore more prone to generate “adverse effects on markets” (La Porta et al., 2007). British common law seems to be associated with better investor protection, lighter government ownership and regulation, and less formalized and more independent judicial system, all of which are in turn associated with more favorable economic outcomes. These characteristics of the common law therefore provide strong incentives to foreign investments from which the economy can substantially gain. On the other hand, a development strategy that aims at benefiting more from openness to trade (e.g. technology spillovers) would favor measures that tilt the trade pattern towards goods that embody technology, and stronger economic ties with advanced countries that perform more R&D activities. These types of government intervention seem to be more consistent with the French civil law.

5 Conclusion

The literature that searches for R&D spillovers has suggested that the return on investment in new technology is not confined within the performing countries, but also some benefits spill over to foreign partners with relatively strong trade or investment ties. Consequently, international knowledge spillovers could offer growth opportunities to developing countries that do little, if any, R&D activity, provided that they develop significant absorption capabilities in order to rip the subsequent benefits.

This paper asks how and why some developing countries may exhibit stronger absorption capabilities of technology spillovers. The key contributions of the paper to the North-South technology spillover literature are threefold. First the paper considers both diffusion channels, namely imports and FDI. Second, it considers additional sources of heterogeneity that have been proven to play a significant role in technology spillover among developed countries, e.g. economic and social institutions. Lastly, the paper uses an improved panel cointegration technique that was not fully worked out a decade ago.

Some key answers based on a panel cointegration setting of 47 developing countries and using the FMOLS estimation technique first suggest that the spillovers gains are quite substantial: a one-percent increase in a developing country's foreign R&D capital stock leads to more than 0.16 percentage increase in its total factor productivity. Much of this spillover gain occurs through the import channel. Additionally, the different estimates do not provide a clear-cut indication as of which type of R&D activity in the performing countries is associated with more spillover gains, although the government-funded R&D seems more often to generate larger benefits.

The results also suggest significant heterogeneity in the spillover gains. Cross country differences have to do with the openness to international trade, the stock of human capital measured by the average years of schooling, and the quality of the institutions (e.g. ease of doing business, property rights, legal traditions). As for policy implications, developing countries wanting to strengthen their absorption capabilities definitely have to design policies that not only take into account the diffusion channels, but also the right set of domestic institutions.

A Data Sources

Data used in this paper come from a variety of commonly used sources. Most of the macroeconomic data are from the World Bank (World Development Indicators, 2008): GDP, gross fixed capital formation, labor force, and total imports of goods and services. Data on bilateral imports of machinery and equipment come from OECD, as well as data on R&D expenditures in the G7 countries, both the total and by sectors. The bilateral FDI flows are obtained from UNCTAD. The average years of schooling up to 2000 are from Barro and Lee (2000).[5] Interpolation is used to both turn the quinquennial data into yearly data, and extend the time span to 2006, by assuming a constant rate of change over a given 5-year segment, and the rate over the period 1996-2000 is applied to the period 2001-2006. The Index of Patent Protection is obtained from Park (2008), and the same interpolation strategy is used to get yearly data.[6] The Ease of Doing Business come from the World Bank for 2006.[7] Data on the historical origin of the legal system come from La Porta et al. (2007).

B List of Developing Countries in the Sample

Table B1: List of developing countries

Africa	Latin America	Asia-Pacific
Benin	Argentina	Bangladesh
Cameroon	Bolivia	China
Central African Rep.	Brazil	Fiji
Congo, Dem. Rep.	Chile	Hong Kong
Egypt	Colombia	India
Ghana	Guatemala	Indonesia
Kenya	Guyana	Jordan
Malawi	Honduras	Korea
Mali	Mexico	Malaysia
Mauritius	Paraguay	Nepal
Niger	Peru	Pakistan
Senegal	Uruguay	Papua New Guinea
Sierra Leone	Venezuela	Philippines
South Africa		Thailand
Sudan		Vietnam
Tanzania		
Togo		
Zambia		
Zimbabwe		

[5] http://www.nber.org/pub/barro.lee/
[6] http://www.american.edu/cas/econ/faculty/park.htm
[7] http://www.doingbusiness.org/economyrankings/

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