Faraway or Nearby?

Domestic and International Spillovers in Patenting and Product Innovation

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Abstract

The diffusion of knowledge plays a central role in endogenous growth theories. Simply put, in these models new knowledge can be generated from preexisting knowledge. In other words, existing knowledge is a pure public good, which can benefit any economic agent anywhere. More generally, endogenous growth theories rely on a broad set of assumptions that have not been tested sufficiently, especially for developing economies. The scope and nature of knowledge spillovers is, however, important for policy, because the presumed positive spillovers can justify government intervention (if the spillovers are localized) or laissez faire (if the spillovers are international). This paper empirically assesses the scope and direction of knowledge spillovers in national patenting and, separately, product innovation by firms. The first set of exercises tests whether the cumulative

knowledge specifications of the knowledge production function can explain international patterns of patenting or whether own research and development is necessary to produce patents. The second set of exercises analyzes whether firm product-quality upgrading and the introduction of new products depend on product innovation within industries, within or across countries. The evidence supports the view that existing stocks of knowledge, domestic and foreign, enhance national innovation and entrepreneurship in the form of product innovation. More specifically, the evidence suggests that within-country and international knowledge spillovers are positive, but international spillovers can be negative for firms that are far from innovative firms in terms of productivity. The results depend on the concept of “distance” between countries and firms.

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Faraway or Nearby? Domestic and International Spillovers in Patenting and Product Innovation*

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1 Introduction

The diffusion of knowledge is central to endogenous growth theories (Romer (1986, 1990); Grossman and Helpman (1991b,a); Rivera-Batiz and Romer (1991)). Due to its public good nature, new knowledge can be generated from all existing knowledge or R&D investments. Despite their appeal, endogenous growth theories rely on a broad set of assumptions that remain untested. For instance, there could be differential effects of knowledge spillovers, depending on the types of innovations and the distance (geographical or technological) between the innovator and the source of existing knowledge. Simply put, it is not obvious that a poor country can easily adopt knowledge from technologically or geographically faraway economies; it is not clear that low-productivity firms can easily learn from firms operating at the technological frontier.

This paper explores the impact of knowledge spillovers on the generation of new knowledge using two types of data: patents granted by the United States Patent and Trademark Office (USPTO) and firm data on product-quality upgrading and the introduction of new goods from the World Bank’s Enterprise Surveys. Although patents might be appropriate to study innovation patterns and externalities in developed countries, they might be ill suited for analyzing innovation patterns in developing countries. Hence both approaches might be more revealing than focusing only on one type of innovation.

In a first set of econometric estimations, following Rivera-Batiz and Romer (1991), we test whether the so-called “cumulative knowledge” or the “R&D investment” function explains patenting activity at the country level. If knowledge spillovers are international, then patenting by one country should be influenced not only by the stock of patents received by nationals, but also by the stock of patents worldwide. More specifically, we estimate specifications of patent functions with elements of the cumulative-knowledge and R&D-investments models, and allow for countries’ patenting activity to be influenced by the accumulated domestic and foreign knowledge. In a second set of estimations with firm data we explore the determinants of product-quality upgrading and the introduction of new products, with a focus on the role of within-country and within-industry spillovers across firms. That is, the empirical strategy on patents exploits the time dimension of the data, and the analysis of quality upgrading and new products by firms exploits the industrial sector classification of the data but not a time dimension since we do not have panel data on firms (from throughout the world). We would have liked to use sectoral data on patents however there is no unique correspondence between patent classes and industrial sectors.

The literature on spillovers has theoretical foundations on models of endogenous growth. These models were first introduced in Romer (1990, 1986), and then subsequently studied by Grossman and Helpman (1991a,b) and Aghion and Howitt (1992) among others. In Romer (1990) the aggregate stock of designs for intermediate inputs changes as a function of the existing stock of designs

and human capital. In this specification, previous knowledge is used as one of the main inputs for new knowledge. A key feature of this specification is that previous knowledge can be accessed at no additional cost, as if it were a pure public good, for producing new designs of intermediate capital goods. This approach has been taken by many others in the development of endogenous growth models. Although this could be a reasonable assumption as a first approximation to the knowledge function within a closed economy, it might be inappropriate in a global context. Importantly, the first attempt to analyze the predictions of endogenous growth models in the context of an open economy were also made implicitly under the closed-economy assumption. Indeed, in their seminal paper Rivera-Batiz and Romer (1991) (RBR henceforth) developed two approaches for the knowledge function of an economy. In particular, in addition to the stock of (domestic) knowledge, the authors included R&D expenditures as an independent explanatory variable that is unaffected (theoretically) by the stock of previous knowledge. When using the cumulative-knowledge production function, RBR assume that knowledge coming from the domestic and the foreign economy are complements and that both generate positive spillovers of equal magnitude.

This paper generalizes the RBR cumulative-knowledge production function by investigating the impact of several sources of existing knowledge on the generation of new knowledge. That is, we split the sources of the stock of knowledge into domestic, regional or income group, and rest of the world. This approach allow us to test if geographical distance or income per capita gaps are relevant notions of distance for the diffusion of knowledge spillovers across countries. The analysis of product innovation by firms adds another dimension of distance, namely the technological distance between firms, which cannot be assessed using the cross-country patent data.

Thus, the paper is related to the literature on innovation, productivity, and knowledge spillovers. Some contributions, including Bernstein and Nadiri (1989), Jaffe et al. (1993), Audrestsch and Feldman (1996), and Branstetter (2001), highlight that knowledge spillovers are partly localized because the ability to receive knowledge is influenced by the distance from the knowledge source. Others, such as Coe and Helpman (1995), Eaton and Kortum (1996), Xu and Wang (1999), Van-Pottelsberghe-De-La-Potterie and Lichtenberg (2001), Keller (2004), Javorcik (2004) and MacGarvie (2006) suggest instead that knowledge flows across countries embodied in international trade flows, either in intermediate input or equipment imports or in final goods.

The analysis of patents seems similar to research by Bottazzi and Peri (2007), who used co-integration techniques to test for a long-run relationship between a country's R&D, its stock of ideas, and the stock of ideas from the rest of the world. They use as sample of fifteen OECD countries for the period 1973-1999. We depart from their analysis by testing directly the validity of the assumptions behind endogenous growth theories rather than its expected consequences. We also test for spillovers from patents stocks and R&D impact on new knowledge. Finally, we estimate panel-count-data models that allow us to deal with the integer nature of patent counts, and the

data cover a large sample that varies between 62 and 112 countries depending on the specification, from 1962-2004. The evidence appears to support both the cumulative knowledge function and the R&D expenditure function.

Following RBR our second exercise is also close to Branstetter (2001) and Griffith et al. (2006) in many respects, particularly regarding the notion of technological distance. Our results show that knowledge spillovers affect the marginal, conditional and joint probability of product-quality upgrading and product innovation. However, the spillover effects decline with a firm's productivity distance from the innovators. We find that the economic impact of technology transfer is, for most of the cases, larger for the introduction of new products than quality upgrading. A one standard deviation increase in quality-spillovers generates, for firms similar to innovators, an increment of 70% points in the conditional probability of doing quality up-grading and raise by 5.3% the probability of innovating only in this dimension. By contrast, a one standard deviation increment in variety-spillovers delivers, for firms close to innovators, an increment of 160% in the conditional probability of introducing a new good and raise 246% the probability of innovating only in this dimension. All these effects are lower for firms that are far from innovators as the estimated coefficients corresponding to the interaction between quality upgrading and product innovation by the most productive firms are negative and statistically significant. Indeed, international knowledge spillovers could be negative for firms far away from the technological frontier.

The rest of this paper is structured as follows. The next section briefly reviews the literature on knowledge production functions and inter-firm spillovers. Section 3 provides a formalization of the theoretical framework. Section 4 presents our empirical approach for our research questions. Section 5 discusses the data sources and the data main characteristics. Section 6 presents our empirical results and section 7 concludes.

2 Related Literature

The existing attempts to test endogenous growth models have not been successful in supporting the theory, thus motivating important critiques. One of the main critiques concerns the scale effect, which should be observable because if (local) existing stocks of knowledge are affect innovation then large countries should growth faster than small economies. Backus et al. (1992) pointed out that larger countries did not grow faster in the postwar era. Jones (1995) used time-series to establish that there have been substantial increases in R&D inputs with no corresponding increase in growth rates. More recently, Bottazzi and Peri (2007) and Yasser and Joutz (2006) using co-integration techniques, indirectly tested endogenous growth theories by testing the implied time series properties of patents, R&D, and Total Factor Productivity (TFP). Bottazzi and Peri (2007) also found evidence against the endogenous growth scale effect in a sample of 15 OECD countries. However, from the

co-integration relationship they derive positive knowledge spillovers from G7 to non-G7 countries and “a somewhat puzzling negative effect” from non-G7 to G7 countries. Yasser and Joutz (2006) investigated the case of the U.S., finding significant inter temporal knowledge spillovers with an elasticity at least as large as one. However, they also found that doubling the stock of patents, a proxy for the stock of knowledge, increases long run TFP by a modest 10%.

There is an extensive literature on the existence of knowledge and R&D spillovers within and across countries. Among early contributions, Bernstein and Nadiri (1989) investigated intra-industry R&D spillovers in four American industries (chemicals, petroleum, machinery, and instruments) during 1965-1978. They found that production costs decline as knowledge expands towards externality-receiving firms, and factor demands change in response to the spillovers. The authors estimated the social and private rates of return to R&D, and found that the social rate exceeded the private rate for the four industries. Coe and Helpman (1995) explored the effects of a country’s R&D capital stock and the R&D capital stocks of its trade partners on a country’s total factor productivity. They employed data for up to 21 OECD countries plus Israel from 1970-1990. The study found large effects of both domestic and foreign R&D capital accumulation on total factor productivity. The effects of foreign R&D capital stocks on domestic productivity seemed to rise with a country’s share of imports over GDP and decline with country size.

Coe and Helpman (1995) emphasized the role of trade in intermediate inputs as a conduit of spillovers. However, a subsequent paper by Keller (2004) that used random measures of bilateral trade to weight the foreign spillover term provided econometric evidence that the import shares are irrelevant for the results in Coe and Helpman (1995), thus shedding some doubt on the trade channel for the transmission of spillovers. Xu and Wang (1999) highlight that technology diffusion in trade models is associated specially with differentiated capital goods trade. Thus, in contrast to Coe and Helpman (1995), who employed overall trade, Xu and Wang (1999) showed that the distinction between capital goods trade and total trade matters. The first one accounts for about 10 percent more of the variation in productivity in domestic industries than Coe and Helpman (1995)’s study, and it also performs better than Keller (2004)’s variable.

There is also an important literature that investigates knowledge spillovers directly, including Jaffe et al. (1993), Branstetter (2001) and Griffith et al. (2006). Jaffe et al. (1993) conduct a detailed analysis to identify where spillovers go. The study involves the comparison of the geographic location of patent citations with that of cited patents. Domestic patents are more likely to be cited by domestic patent applications and more likely to come from the same state. In a related paper, Audrestsch and Feldman (1996) examine the extent to which industrial activity clusters spatially, and the link between geographic concentration and the existence of knowledge spillovers. The study relies on the Small Business Administration’s Innovation Data Base, which compiles data for up to 8,074 commercial innovations introduced in the United States during 1982. The authors employed

citation data to locate innovations across states. The study concludes that innovative activity tends to cluster more in industries where knowledge spillovers play a decisive role, thus confirming the hypothesis that the ability to receive knowledge externalities is influenced by the distance from the knowledge source, which in turn generates geographic concentration of production.

Branstetter (2001) provided new estimates of the relative impact of domestic and international knowledge spillovers on innovation and productivity at the firm level. His study uses micro data on publicly traded high-technology manufacturing firms in the United States and Japan during the period 1977-1989. The results provide strong evidence on intra-national knowledge spillovers. There is limited evidence that Japanese companies, for example, benefit positively from research undertaken by American firms, and there is no evidence that American companies benefit positively from research conducted by Japanese companies. In fact, when the last effect is statistically distinguishable from zero, it is negative. This seems to be an important result within the literature on spillovers. We will discuss more extensively the mechanisms for negative knowledge spillovers in our results section.

Similarly, Griffith et al. (2006) investigates how much firms in the United Kingdom benefit from U.S. R&D with panel data. The authors found that U.K. firms benefit significantly from U.S. R&D. In contrast, the opposite flow of knowledge seems not to generate such benefits for U.S. firms. The evidence supports the hypothesis of international spillovers with strong idiosyncratic components. They also find that industries in the UK whose productivity lags behind with respect to the U.S. benefit the most; however surprising this result might be, it highlights the importance of controlling for technological distance between firms.

Botazzi and Peri (2003) discuss plausible impacts of existing knowledge on the generation of new ideas. They argue that they can be positive, negative or zero due to two opposing effects. First, existing ideas can broaden the base of useful knowledge available to generate new innovations in the future. Alternatively, if the best ideas are the first to be discovered, then a larger stock of knowledge implies that it is going to be harder to find new ideas. While the first effect suggests a positive relationship between the knowledge stock and production of new knowledge, the second acts in the opposite direction, decreasing the production of knowledge as more knowledge is available. Finally, the separation of the stock of knowledge accumulated in the country as the rest of the world is done to allow the possibility that these effects can differ or even have opposing effects.

From a broader perspective we can argue that new knowledge can be a complement or a substitute for existing knowledge. While in some cases knowledge itself can be useful to create new inventions behaving as complements, the instruments in which knowledge is embedded can be exclusive, or might have market consequences that can undermine the generation of new knowledge. Patents, for example, are exclusive in the sense that once it has been granted nobody else can patent the same innovation (for the same stated commercial purpose). This is a well known effect studied

in patent races theories. Thus, another firm's probability of patenting when it is doing R&D in the same area might decrease. Furthermore, the exclusive rights granted to patent holders might have long-lasting effects, whereby the patent holder gains a competitive advantage in producing other related inventions, thus further limiting patenting by other firms or countries (see Grossman and Helpman (1991b)).

In sum, despite the fact that the endogenous growth literature and the knowledge spillovers literature have focused for the most part on positive knowledge spillovers, there are several reasons why these could be negative, especially for the case of patenting. In the case of product innovation, we cannot overstate the aforementioned concerns about the impact of innovating firms on firms that are technologically faraway. Thus, it is an empirical matter whether spillovers are positive or negative.

3 Analytical Framework

Our empirical work is motivated by the endogenous growth literature. As mentioned, there are two main approaches, the cumulative knowledge approach and the laboratory equipment approach. These have been used by Romer (1990) and Rivera-Batiz and Romer (1991) and Grossman and Helpman (1991b) among others. The work of Rivera Batiz and Romer is the main theoretical background needed to motivate our empirical section. In particular, their work deals not just with innovation and growth, but also with international integration and its impact across countries.

In the case of a single economy, the model establishes the following functional form for the case of cumulative knowledge production function: $\dot{A} = \delta AH$, where A represents the stock of knowledge ("designs" in the words of the authors) and the dot over it indicates a change in this stock. δ is a productivity parameter, and H is the skilled labor used in the production of knowledge. The change in or flow of designs is a function of all the stock of intermediate designs. Hence, knowledge represented by the number of existing designs behaves as a public good.

On the other hand, the R&D-investment knowledge production function is modeled as $\dot{A} = BH^\alpha L^\beta \int_0^A x(i)^{1-\alpha-\beta} di$, where H is skilled labor, L is unskilled labor and $x(i)$ are the capital goods produced. B is a constant scale factor. In this approach the capital goods ($x(i)$) (think of laboratory equipment such as computers, scan machines, microscopes, etc) play a central role in the production of new knowledge (or designs), but, most importantly, previous knowledge plays no role and has no productive value.

So far we have presented the knowledge production function for a closed economy. Certainly international integration via trade affects the availability of intermediate inputs, and openness in communication channels play a central role in the knowledge diffusion between economies. Rivera Batiz and Romer were the first to model, under the assumptions presented thus far, the consequences

of international integration on growth. Adding some notation, with the asterisk denoting variables from a foreign economy, the cumulative knowledge production function changes to: $\dot{A} = \delta(A+A^*)H$, where A^* is the stock of knowledge in the foreign economy. The relevance of this specification is that domestic and foreign knowledge are accumulative, and both are used in the production of domestic capital goods designs. Indeed, this specification not only considers that domestic and foreign knowledge behave as complements to each other and there is no overlap nor competition for ideas, but also that these two stocks of knowledge have the same positive impact on the production of new knowledge.

In the case of laboratory equipment the new production function for knowledge is given by $\dot{A} = BH^\alpha L^\beta \left(\int_0^A x(i)^{1-\alpha-\beta} + \int_0^{A^*} x(i)^{1-\alpha-\beta} \right) di$. In this case the availability of foreign capital goods affects (via trade) the knowledge production function for domestic intermediate capital goods. Thus, the right hand side term corresponds to the R&D level of expenditure in the domestic economy.

The first set of estimations (see Section 4 below) on patent functions tests the cumulative knowledge and laboratory equipment approaches. In our second set of exercises, we test whether two other particular types of innovations behave as the cumulative knowledge production function for new innovations, distinguishing again between national and international sources of knowledge. In the absence of R&D expenditure data at the firm level, in this second exercise we test only whether the cumulative knowledge production function is a reasonable approach for the generation of two particular types of innovation: quality upgrading and new goods creation.

4 Empirical Strategies

The following subsections discuss the econometric models. The first set of issues concerns the estimation of patent functions, and the second is on the estimation of inter-firm spillovers focused on product innovations.

4.1 Patents and externalities

Although attempts to test endogenous growth theory and its assumptions directly are rare, there is a long literature on the estimation of patent-knowledge production functions. Due to the discrete and non-negative nature of patent counts, the estimation of the contribution of innovative effort or other inputs to the production of patents has often been conducted with count data models, either with Poisson or Negative Binomial estimators (Griliches (1990), Hall et al. (1986)). However, recent work has also utilized log-linear specifications that estimate the dynamics of the patent production process through econometric techniques such as GMM-System or simply by OLS or TS-LS, under the assumption that the proportion of zeros in the sample is small (Bosch et al. (2005) y Botazzi and Peri (2003)). A cross sectional stylized fact is that the relationship between patents and R&D

has an elasticity close to unity. However, once you include the time dimension, the relationship becomes weaker with elasticities smaller than one.

Pakes and Griliches (1980), Hall et al. (1984) and Hall et al. (1986) were the first to study the relationship between patents and R&D, focusing on the time dependence between these variables at the firm level. A common result in these studies is that the impact of R&D has a "U" shape: R&D invested during the first and the last years tend to have a positive and significant impact on firm patenting, but the expenditure incurred between these years seems to have little effect. The estimation of Pakes and Griliches (1980), performed with a linear model with data from 121 U.S. companies, indicates that the elasticity of the sum of contemporaneous and lagged R&D is significant and close to 0.6. Hall et al. (1984) and Hall et al. (1986) estimate the relationship between patents and R&D using Poisson and Negative Binomial models for a broader group of U.S. firms. They find that when controlling for fixed effects the elasticity of the sum of contemporaneous and lagged R&D is smaller than that found by Pakes and Griliches (1980), with estimates between 0.3 and 0.5. Jaffe (1986), unlike previous work, used only current R&D expenditure in the knowledge production function, as well as technological spillovers. Jaffe's estimated elasticity of patents with respect to R&D, controlling for fixed effects, is equal to 0.4, but the effect rises with the R&D of other firms.

Blundell et al. (1995) developed an alternative GMM estimator in which the unobservable fixed effect of firms is approximated by the history of patents prior to the period of the estimation sample, namely a pre-sample mean estimator. Blundell et al. (2002) used this estimator in a dynamic context finding elasticities around 0.5. This pre-sample mean estimator is the closest approach to endogenous growth models as it takes into account previous patents as a determinant of current patent counts.

At the aggregate level, Botazzi and Peri (2003), using cross-sectional data for Europe, find elasticities close to 0.8 for the relationship between patents and R&D. Moreover, they find spillovers within 300 kilometers. Bosch et al. (2005) used a panel of 49 countries, using various techniques to estimate elasticities that vary between 0.44 and 0.96. The estimates include static and dynamic specifications, as well as the pre-sample mean estimator, models of count data (with Poisson and negative binomial distributions) and linear GMM.

As mentioned, we address the possibility of multiple sources of patent spillovers. In particular, we consider the following variables: (i) stock of patents from countries of the same income group or region, and (ii) the stock of patents in the remaining income groups or regions of the world. We denote by SP the stocks of patents. In a first stage, we estimate global knowledge spillovers on national patent counts by estimating the following function, which generally corresponds to count-data estimators:

$$P_{i,t} = \Phi(\alpha_0 SP_{i,t-1} + \alpha_1 SP_{World,t-1,-jt}, d_t, u_i, \epsilon_{i,t}) \quad (1)$$

where subscript i indexes countries, j represents income group and t is time (year). The variable SP

stands for the stock of patents, for both the country and the rest of the world. u_i is country fixed effect, which we include in some of the estimations (see 6 below). In turn, we explore the possible knowledge spillovers emanating from the region or income group:

$$P_{i,t} = \Phi(\alpha_0 SP_{i,t-1} + \alpha_1 SP_{j,t-1,-it} + \alpha_2 SP_{World,t-1,-jt}, d_t, u_i, \epsilon_{i,t}) \quad (2)$$

In this case the specification includes the stock of patents accumulated by the country, other countries in the same income or regional group, and the stock from the rest of the world.

In a second step we estimate the R&D specification that is analogous to RBR's laboratory equipment:

$$P_{i,t} = \Phi(\beta_0 RD_{i,t}, d_t, u_i, \epsilon_{i,t}) \quad (3)$$

And the nested models specification (with two country groups, one by income and another by region, denoted by subscript $j2$) is given by:

$$P_{i,t} = \Phi(\beta_0 RD_{i,t} + \alpha_0 SP_{j,t-1} + \alpha_1 SP_{j2,t-1} + \alpha_2 SP_{World,t-1,-jt}, d_t, u_i, \epsilon_{i,t}) \quad (4)$$

If knowledge spillovers are positive, then $\alpha_0, \alpha_1, \alpha_2 > 0$. However, the coefficients on foreign patent stocks could be zero or negative if instead of complementarity in knowledge, as is assumed in endogenous growth models, there is some degree of substitutability between the research carried out in a given country and the research carried out in the rest of the region or the rest of the world. This would happen, for example, if there is competition for patents across countries and if this effect dominates the public-good diffusion effect.

Finally, the choice of econometric estimators is not trivial. As mentioned above, various contributions have utilized count-data models, mainly Poisson or Negative Binomial estimators. Since country-specific effects (and time effects) play an important role in our application, we provide estimates of equations 2 and 4 above with a Negative Binomial estimator as proposed by Allison and Waterman (2002). The main difference with respect to Hall et al. (1984) concerns how one controls for country fixed effects. Allison and Waterman (2002) show simulation evidence indicating that the Negative Binomial estimator with dummy variables used to control for unit-specific fixed effects is superior to the estimator proposed by Hall et al. (1984). This is due to the fact that, in the presence of overdispersion in the data generation process, fixed effects affect the model prediction through two channels. One is the correlation between the unit fixed effects and the explanatory variables of interest, and the second is through the over-dispersion parameter. The approach proposed by Hall et al. (1984), which relies on unit-specific over-time average patent counts to control for unit-specific fixed effects does not control for biases due to the influence of fixed effects on the over-dispersion parameter. Hence, our estimations come from the Negative Binomial estimator with

country dummy variables used to control for country-specific fixed effects.

4.2 Product innovation and spillovers between firms

Our second set of estimations builds on previous research on spillovers by Jaffe et al. (1993), Branstetter (2001) and Griffith et al. (2006). This literature argues that knowledge spillovers between two firms should be proportional to the similarity and intensity of their research programs and related to geographical distance between the source and the receiver of the spillover. To capture these effects, these papers construct a measure of technological proximity between firms or split sources of spillovers between local, national and international. For technological similarity they use the uncentered correlation coefficient between firms' vectors of R&D expenditures. Additionally, all these papers use patent citation data to identify the direction of knowledge flows.

Unfortunately, we are not able to follow completely Branstetter (2001) and Griffith et al. (2006) as we do not have information about the way firms allocate R&D expenditures across technological categories. To overcome this drawback, we work under the assumption that if two firms operating in the same country and industry are equally productive, they are involved in similar research projects. Therefore, we measure technological proximity between two firms by comparing their productivities, although we do not compute productivity per se but work with a set of productivity correlates. Many studies show that more than one factor determines the productivity of a firm. Clerides et al. (1998) and Bernard and Bradford (1999) provide evidence that exporters are more productive. Feenstra and Hanson (1997) show that affiliates of multinational corporations outperform domestic firms in recipient countries; Almeida and Fernandes (2008) report that majority foreign-owned firms are less likely to engage in technological innovations than minority foreign-owned ones, and Brambilla (2006) finds that firms with more than 50 percent of foreign ownership introduce on average more than twice as many more new products as private domestic companies. Finally, Cohen and Kelpner (1996) report that the likelihood of a firm reporting positive R&D efforts rises with firm size.

Thus, we consider several correlates of productivity to construct a proxy of technological distance between firms. More precisely, the index is the first principal component of the following variables: a dummy that takes value 1 if the firm is an exporter and 0 otherwise, a dummy that takes value 1 if the firm is foreign owned and 0 otherwise, a dummy that takes value 1 if the firm invests in R&D and 0 otherwise, a dummy that takes value 1 if the firm holds technological licenses and 0 otherwise, and the logarithm of the firm's labor force (since size and productivity are expected to be correlated). The index is defined as the predicted value for the first component in the principal component analysis of these variables. Table 1 displays the loadings corresponding to each input. In turn, the technological distance between firm i and j , d_{ij} , is the absolute value of the difference between their predicted productivities.

4.2.1 Domestic knowledge spillovers

For any firm i that belongs to country c and operates in industry z ; we measure intra-industry knowledge spillovers in innovation of type x , with $x = \{quality, variety\}$, by the number of firms, different from i , that belongs to industry z and conduct innovations of type x ,

$$K_{iczx}^{dom} = \sum_{j \neq i, j \in c, j \in z} I_{jczx}, \quad (5)$$

where I_{jczx} is a dummy variable that takes value 1 if firm j innovates in dimension x and 0 otherwise. To test if the technological proximity of a firm to the knowledge source affects its ability to appropriate knowledge, we interact the previous variable with a measure of technological distance between two firms. This gives us the following variable:

$$K_{iczx}^{adj-dom} = d_{izx}^{Av} K_{iczx}, \quad (6)$$

where d_{izx}^{Av} is the absolute value of the difference between the productivity of firm i and the average of x -innovators' productivities.

4.2.2 International knowledge spillovers

To measure the impact of international knowledge spillovers, we follow the criteria described in the previous section. However, to control for geographic distance, which might dampen the transfer of tacit knowledge (see Audrestsch and Feldman (1996)), and to take into consideration that the probability that two countries engage in trade depend negatively on the distance between them, we weigh the knowledge spillovers variable by the inverse of the distance between trading partners. Thus, for any firm i that belongs to country c and operates in industry z , the international intra-industry knowledge spillovers in innovation of type x are as follows,

$$K_{czx}^{int} = \sum_{p \neq c, p \in P} \frac{1}{d_{cp}^{geo}} K_{pzx}, \quad (7)$$

where K_{pzx} is the number of firms in industry z and country p that report innovations of type x ; d_{cp}^{geo} is the geographic distance between countries c and p ; and P is the set of countries included in the sample. To analyze the extent to which technological proximity affects the ability of a firm to appropriate knowledge from others; we construct the following variable,

$$K_{iczx}^{adj-int} = \sum_{p \neq c, p \in P} d_{ipzx}^{Av} K_{czx}^{int}, \quad (8)$$

where d_{ipzx}^{Av} is the absolute value of the difference between firm i 's productivity and the average of x -innovators' productivities in country p and industry z .

4.2.3 Quality upgrading, new products and spillovers

The empirical model we estimate is a two-equation system of two Probit models with a common error components. In other words, the model estimates the determinants of the probability of product upgrading and product innovation by firms, allowing for these two decisions by the same firm to be correlated. More formally, the empirical model can be written as follows:

$$IQ_{izct}^* = \beta_1 K_{iczQt}^{dom} + \beta_2 K_{iczQt}^{adj-dom} + \beta_3 K_{czQt}^{int} + \beta_4 K_{iczQt}^{adj-int} + \beta_x \mathbf{X}_{iczt} + \beta_z \mathbf{Z}_{czt} + \beta_{dc} \mathbf{D}_{ct} + \beta_{dz} \mathbf{D}_z + \varepsilon_{iczt}^Q,$$

$$IV_{izct}^* = \gamma_1 K_{iczVt}^{dom} + \gamma_2 K_{iczVt}^{adj-dom} + \gamma_3 K_{czVt}^{int} + \gamma_4 K_{iczVt}^{adj-int} + \gamma_x \mathbf{X}_{iczt} + \gamma_z \mathbf{Z}_{czt} + \gamma_{dc} \mathbf{D}_{ct} + \gamma_{dz} \mathbf{D}_z + \varepsilon_{iczt}^V,$$

$IQ_{izct} = 1$ if $IQ_{izct}^* > 0$, and 0 otherwise,

$IV_{izct} = 1$ if $IV_{izct}^* > 0$, and 0 otherwise,

$$E[\varepsilon_{iczt}^Q | \Theta] = E[\varepsilon_{iczt}^V | \Theta] = 0,$$

$$V[\varepsilon_{iczt}^Q | \Theta] = V[\varepsilon_{iczt}^V | \Theta] = 1,$$

$$Cov[\varepsilon_{iczt}^Q, \varepsilon_{iczt}^V | \Theta] = \rho.$$

Θ is the set of all explanatory variables. IQ_{izct} is a dummy variable that equals 1 if firm i of industry z and country c upgrades the quality of an existing product at time t and 0 otherwise. Likewise, IV_{izct} is a dummy variable identifying firms that introduced a new product. $\mathbf{X}_{iczt}$ is a vector of firm characteristics, which includes the variables used to construct the productivity index and numerous additional control variables: a dummy for firms that report obstacles in access to finance, a dummy that identifies firms that claim that economic and regulatory policy uncertainty is an obstacle, a dummy for access to business licenses or permits as an obstacle for the firm, a dummy for firms that report that anti-competitive pressures are an obstacle for the firm, and a dummy for when the lack of intellectual property rights protection is an obstacle for the firm and 0 otherwise.¹

Vector $\mathbf{Z}_{czt}$ controls for country-industry characteristics that the literature finds relevant. These variables capture the effects of competition, investment climate, and credit constraints. Leading

¹The Appendix presents a detailed description of each variable.

papers in this literature include Nickell (1996), Blundell et al. (1999), Griffith et al. (2004), Aghion et al. (1999), which show that competition affects innovation. Other papers, such as Lederman (2009), argue that the investment climate matters as a determinant of R&D effort. Another group of papers, including Aghion et al. (1997) and Aghion and Howitt (1992), shows that credit constraints affect the cyclicalities of R&D investments, and the degree of financial development affects the introduction of new products, both for incumbent and new firms. Thus, vector $\mathbf{Z}_{czt}$ includes variables such as a Herfindhal index of sales, the percentage of firms that have difficulties to access financing, the percentage of firms that report difficulties in obtaining business licenses, the percentage of firms that worry about anti-competitive practices, the percentage of firms with foreign ownership, the percentage of firms with managers as the largest shareholders, the percentage of exporter firms, intellectual property right protection of trade partners, GDP per capita of trade partners, international backward linkages, and international forward linkages. The models are thus heavily parameterized, because the cross-sectional data do not allow us to control for firm fixed effects, and thus it is safe to err on the side of caution.

Finally, an important feature of this empirical strategy is that innovation in one dimension can affect the probability of innovation in the other; a firm's introduction of a new product variety can affect its propensity to upgrade existing products, and vice versa.

5 Data

The data on patents were taken from United States Patent and Trademark Office (USPTO) yearly statistics and cover the period 1963 to 2004. The R&D expenditure data were taken from Lederman and Saenz (2005) and updated with UNESCO data from its web site. The human capital related variables were taken from the World Bank's World Development Indicators. We compute the stock of patents using the perpetual inventory method. The depreciation rate is assumed to be equal to 15%, which implies that the 90% of each patent is extinguished at the end of a 15-year period. Spillover variables for the stock of patents are computed considering different levels of aggregation over the world total stock or expenditure. Since the patent counts by country and year come from the USPTO, it is worthwhile to control for exports to the United States. This variable can be interpreted as a proxy for a country's inventors to file patent applications with the USPTO. That is, the higher are the merchandise sales in the U.S. market, the stronger is the incentive to submit patent applications to the USPTO. As discussed in the results section 6.1, some coefficient estimates do appear to be sensitive to the inclusion of this variable. The data for exports to the U.S. come from the International Monetary Fund's *Direction of Trade Statistics*.

Table 2 shows the R&D effort across selected economies and regions. The most noticeable characteristic of the patterns of R&D is the significant difference between developed and develop-

ing countries. The OECD countries invested an average of 2.30% of the GDP during the period 1963-1969, by the beginning of this century they had slightly increased R&D to 2.58% of GDP. Scandinavian countries increased from 1.43% to 3.16% during the same period. In contrast, developing regions such as Latin America and the Caribbean or Africa have kept their R&D effort well below 1% during the same period. In particular, Latin America increased its R&D effort from 0.47% in the 1960s to 0.65% of GDP at the beginning of this century, while Sub-Saharan Africa passed from 0.24% to 0.63% of GDP. Table 2 also shows the R&D effort from leading economies. During the period 1963-2004 Japan increased its R&D expenditure from 1.95% to 3.31%; Israel increased from 1.03% to 4.71% of GDP, and the Republic of Korea increased from 0.45% to 3.54% during the same period.

Table 3 shows R&D expenditures per capita for the same group of countries and regions of Table 2. The difference between developed and developing countries is more striking than in Table 2. While Sub-Saharan Africa invested 14.2 dollars per capita and Latin America and the Caribbean invested 22.2 dollars per capita, developed countries invested several hundreds of dollars per capita. In particular, OECD countries invested 533.5 dollars per capita and Scandinavian countries 941 dollars per capita.

Table 4 shows the yearly average number of patents for the period 1963-2004. The number of patents from developed countries is several orders of magnitude larger than patents from developing countries. While the OECD patented 5581 inventions per year during the period 2000-2004, Sub-Saharan African countries patented an average of 2.5 patents and Latin America and the Caribbean 258.4. Furthermore, the developed economies more than doubled their number of patents per year since the 1960s. The estimations are conducted with a panel of five-year periods, and thus the estimations cover data from 1963-2002.

For the estimations of inter-firm spillovers we employ data from the Enterprise Surveys to estimate the magnitude (and direction) of intra-industry domestic and international knowledge spillovers at the firm level. The surveys were conducted by the World Bank, and they are designed to capture business perceptions about the biggest obstacles to enterprise growth, the relative importance of various constraints to increase employment and productivity, and the effects of a country's business environment on its international competitiveness. Each survey was completed by managing directors, accountants, human resource managers and other company staff. The core survey is organized into two parts. The first part seeks managers' opinions on the main constraints in the business environment. The second part focuses on productivity measures. The Enterprise Surveys sample from the universe of registered businesses and follow a stratified random sampling methodology. A small number of sectoral sub-samples are included to provide measures of productivity that can be compared across countries (within industries). Because the distribution of establishments in most countries is overwhelmingly populated by small and medium enterprises, surveys generally

over-sample large establishments. Sample sizes for enterprise surveys range from 250-1,500 firms by country.

The Enterprise Survey data provide information about innovation in developed and developing countries. It allows us to study the effect of knowledge spillovers in countries that have the most to gain from the knowledge of others. The other advantage is that it gives us the possibility to examine the existence of international knowledge spillovers on a wider base. This is in stark contrast with previous works, which explore the issue using two-country studies. In addition, the surveys collect information on more than one type of innovation, which allows us to compare the economic impact of spillovers across different dimensions of product innovation. The resulting data set is a cross-section of 17,271 firms, from 72 countries from 2003-2006.

Tables 5 and 6 show the share of firms engaged in quality and variety innovations across regions and industries. A large proportion of firms report quality and variety innovations. However, there is substantial heterogeneity across regions. The Sub-Saharan Africa and Latin America and Caribbean regions have the largest propensities to introduce new products, 52% and 56%, respectively. While the Middle East and North Africa zone has the lowest one, 16%. Europe and Central Asia and the Pacific areas have the highest share of firms innovating to improve the quality of existing products, 60%. While the Latin America and Caribbean region registers the lowest one, 33%.

Industries such as Textiles, Beverage, Auto and auto components, and Other transports show propensities to up-grade the quality of existing products that exceed 66%. While the Food and Other manufactures industries display the lowest shares, 38% and 17%, respectively. There is not much variation in the percentage of firms that perform variety-innovations across sectors. The lowest percentage is registered for the Paper industry, 30%, while the highest share is reported for the Food sector. Finally, Table 7 presents summary statistics of the main variables.

6 Results

As mentioned, we report results on patents and product innovation separately. The following subsection focuses on patents at the country level, followed by the discussion of the results on product innovation by firms.

6.1 Patents

Tables 8 and 9 present Negative Binomial estimates of the patent function with country fixed effects as in Allison and Waterman (2002), which is a superior estimator than the FE estimator proposed by Hall et al. (1984).² In both tables, the specification test for over-dispersion indicates that we can

²In Hall et al. (1984), fixed effects are included in the form of the over-time average number of patent counts (by country). However, this approach does not control for the indirect effect of country-specific effects through the over-dispersion parameter. See Allison and Waterman (2002) for details.

safely reject the null hypothesis of no overdispersion in the error terms (with respect to the expected number of patents). The key difference between Tables 8 and 9 is that the latter includes domestic R&D as a regressor. In general, the results are unsurprising and consistent with the intuition of the endogenous growth literature. However, the results also show that caution is warranted for inference as variations in the specification of the model alter the results. In what follows, we discuss the cumulative knowledge and R&D functions separately, and given the evidence that both models simultaneously explain patent production we analyze more carefully the results of the nested (joint) model.

Table 8 reports results for the cumulative knowledge production function within countries, with and without time effects, but without R&D. Contrasts between the results without and with time effects demonstrate the importance of controlling for time effects (in addition to country fixed effects) as the results change across specifications. For instance, in column 2, a country's own stock of patents appears with an estimated elasticity just below 0.4, whereas the estimated elasticity in column 3, which controls for time effects, is almost 0.55.

Nonetheless, robust results confirm the positive effect of the stock of domestic patents. Its elasticity remains statistically significant across all specifications presented in Table 8, including those that control for tertiary-schooling enrollment rates (columns 2-8) and exports to the U.S. (columns 6 and 8). In contrast, in the third column of Table 8, the stock of patents from the rest of the world appears with a negative sign, but it is not statistically significant. This result changes after breaking down the effect from the rest of the world into the effect derived from the same income group or the same geographic region and the rest of the world. Specifically, the estimated elasticity of the stock of patents from countries in the same income group becomes positive after controlling for time effects in column 5, but its significance fades away after controlling for exports to the U.S. in column 6. In columns 5 and 6, the stock of patents from the rest of the world appear with positive and statistically significant coefficients. The latter could be interpreted as evidence that knowledge accumulated in the rest of the world but in countries that do not belong to same income group raises the frequency of patenting in a given economy.

In turn, the elasticity of the stock of patents from countries in the same geographic group (as per the World Bank's regional categories) is reported under columns 7 and 8 (without and with the control for exports to the U.S.) in Table 8. The corresponding elasticities appear to be positive and strongly significant. Thus, the effects derived from the stocks of knowledge from the same income group or geographic region are positive, but they are not significant from the remaining countries of the world in columns 7 and 8.

Table 9 contains the results of R&D patent production functions and the nested models, which simultaneously include the R&D variable together with the accumulated stock of patents from the rest of the world. The first two columns test the R&D model. The first column of Table 9 presents

the elasticity of patents with respect to investment in research and development (R&D) only with each country's own stock of patents and country-specific effects. The elasticities of the own stock of patents and the R&D variables are positive and significant. Column 2 shows the results with country and time-period effects. The magnitude of the estimated elasticity of R&D is similar across these two specifications; the elasticity of a country's own stock of patents is notably higher than the specification under column 1. In fact, the estimated elasticity on R&D is quite robust across all specifications reported in Table 9.

In contrast with the results reported in Table 8, once we control for an economy's own R&D effort, the estimated coefficient for the tertiary-enrollment variable is no longer robust as its significance tends to fall sharply when time effects are included (in columns 5,7 and 10). This is intuitive since there is a high correlation between enrollment rates in tertiary schooling and R&D investment. The latter appears to be a more robust predictor of patenting.

Columns 4-11 of Table 9 report the results for the R&D model augmented by the accumulated stock of patents from the rest of the world. The estimated elasticity of the stock of patents from the rest of the world is negative and statistically significant in column 4, which reports the specification without time effects. This result is reversed in column 5, which includes time effects, thus suggesting that the estimated elasticity of the stock of patents from the rest of world is not robust. It is noteworthy that the estimated elasticities of the own stock of patents and the R&D investment variables seem to be unaffected by the inclusion of the stock of patents from the rest of world. This can be discerned by comparing the results in column 2 with those reported in column 5. However, splitting the stock of patents from the rest of world into those belonging to the same income or geographic group changes the picture substantially. In column 7, the estimated elasticities of the same income group and the one for the rest of world are both positive and significant. In addition, in this specification, the elasticity with respect to own-country stock of patents is relatively high at 0.76, when contrasted to all other estimates. Still, the only plausible explanation of why both components of the stock of patents from the rest of world appear to positively and significantly correlated with the flow of patents in a given country seems to be through the implicit effects operating via the over-dispersion parameter. Further clarity is gained by looking at the results reported in columns 10 and 11, which divide the global stock of patents into those from an economy's geographic group and those from the rest of world. Both specifications include time effects, as well as the country-specific effects. The only difference is that the specification reported in column 11 also includes the variable on exports to the U.S. market, which turned out to be not significant. In both specifications, the stock of patents from a country's own geographic group appears with a positive and statistically significant elasticity of about 0.3, whereas the elasticity of the stock of patents from the rest of the world is negative and significant. We acknowledged above that it might be counter-intuitive that existing knowledge, from wherever it might be, could have a negative effect on the flow of

current knowledge. However, this could easily be the case if there are patent races, a term used to characterize a situation in which rival research teams compete to patent similar innovations (Grossman and Helpman 1991b). Finally, the point estimates of the elasticity of the same-region's spillover effects are approximately equal to the absolute value of the (negative) elasticity of the stock of patents from elsewhere in the world.

6.2 Quality upgrading and new products

Tables 10-12 show our results for the case of national and international spillovers derived from quality upgrading and product innovation. Table 10 presents the marginal effects when we control only for firm characteristics. Table 11 shows the marginal effects after controlling for industry-country variables, as well as country-year and industry effects. Table 12 shows the standardized marginal coefficients from Table 11, so that they provide estimates of the impact of a one-standard deviation increase of an explanatory variable on the probability of observing a product innovation by the firm. Our discussion covers the results of the last two tables, since they present the most complete specification.

Tables 11 and 12 show that the sign and statistical significance of the estimated coefficients are as expected. In these tables IQ denotes quality innovations and IV denotes variety innovations. The tables show that knowledge spillovers are significant at 1% and 5% level; they affect positively the conditional and joint probabilities of innovating in quality and variety. However, their effects are lower for firms that are faraway from innovators in terms of the productivity-correlates index.

Our results show that the economic impact of technology transfer is, for most of the cases, larger when it comes to the creation of new products than for the improvement of existing goods. This is a novel finding. A one standard deviation increase in spillovers generates, for firms close to innovators, an increment of 31% in the probability of being successful in vertical innovations. However, the same variation causes the probability of innovating in the horizontal dimension to increase by 250%.

Two different effects can affect the probability of innovating in one dimension given that a firm has innovated in the other. On the one hand, having innovated may give a firm some general experience that allows it to appropriate easily the knowledge of others. On the other hand, previous experience can make the stock of public knowledge less useful for experienced researchers. If the first effect dominates the second one, we would expect knowledge spillovers to have a larger impact on the conditional probability of innovating than on the probability of innovating only in one dimension. Otherwise, we would expect the reverse effect. .

Interestingly, the first situation characterizes the impact of quality-spillovers, while the second one characterizes the effect of variety-spillovers. This is another novel empirical result. From table 12, a one standard deviation increase in quality-spillovers generates, for firms similar to innovators, an increment of 70% in the conditional probability of doing quality up-grading and raise by 5.3% the

probability of innovating only in this dimension. In contrast, a one standard deviation increment in variety-spillovers delivers, for firms close to innovators, an increment of 160% in the conditional probability of introducing a new good and raises by 246% the probability of innovating only in this dimension. All these effects are lower for firms that are far from innovators as the estimated coefficients corresponding to the interaction terms are negative and statistically significant.

A comparison of the difference between the marginal effects of quality spillovers on $Pr(IQ = 1, V = 1)$ and $Pr(IQ = 1, V = 0)$, with the difference between the marginal effects of variety spillovers on $Pr(IQ = 1, V = 1)$ and $Pr(IQ = 0, V = 1)$ reveals that the first type of spillovers induce firms to choose diversifying innovative strategies. The second type encourages firms to focus the innovative strategy only in one dimension. According to Table 12, $Pr(IQ = 1, V = 1) - Pr(IQ = 1, V = 0) = 0.16 > 0$ for quality-spillovers, while $Pr(IQ = 1, V = 1) - Pr(IQ = 0, V = 1) = -2.45 < 0$ for variety spillovers.

Regarding the impact of international knowledge spillovers, the results show that the effects of spillovers vary across the two dimensions of the innovation process. There is no evidence that quality-spillovers from foreign companies play a significant role to encourage domestic innovations in this direction. However, we do find evidence of positive effects on the propensity to introduce new products. According to Table 12, a one standard deviation increase in spillovers generates, for firms close to innovators, an increment of 10% points in the marginal probability of inventing a new good. However, this effect becomes negative for firms whose productivities are faraway from the average of foreign innovators' productivities by 0.012 points.

7 Conclusions

Despite its wide appeal, endogenous growth theories rely on a broad set of assumptions that remain largely untested, at least from the viewpoint of developing countries. In particular, the functional form of the knowledge production function has not been tested directly.

In their seminal paper, Rivera-Batiz and Romer (1991) presented an extension of the knowledge generating function for the case of two integrated economies. They considered a cumulative knowledge production function in which the input knowledge comes from these two countries, and these inputs have *equal and positive impact* on the generation of new knowledge. However, in an international context differential effects of knowledge spillovers are plausible. Thus, in the first part of this paper we tested the cumulative knowledge specifications with domestic and international sources of accumulated knowledge embodied in patents. The results suggest that the stock of patents of a country affects significantly its current (and future) production of patents, which is consistent with endogenous growth. We also confirmed that there are significant spillovers from the stocks of knowledge from the rest of the world. After separating the source of spillovers by country

income groups or geographic regions, we found positive spillovers from the same geographic region and potentially negative from the rest of the world. On the one hand, this confirms the insight from RBR that the global stock of knowledge is relevant, but on the other hand refutes the idea that all knowledge generates positive spillovers. In addition, the evidence suggests that own R&D investments tend to spur the generation of new patents. Both sets of results suggest that even in developing countries there might be scope for public policy to help finance private R&D investment, partly because the effects of foreign accumulated knowledge on a developing economy's knowledge generation might not bring the expected positive spillovers.

The second set of empirical analyses explored firms' decisions on quality upgrading and the introduction of new goods by focusing on their dependence on the performance of other firms within industries, be they domestic or foreign firms, consistent with RBR. This approach attempted to capture the extent of knowledge spillovers based on the cumulative knowledge production function. We also explored the role of technological distance. The results showed that knowledge spillovers are a significant correlate of product-quality upgrading and product-variety innovation. The estimates suggested that they affect positively the marginal, conditional, and joint probabilities of innovating in quality and variety. However, their effects are lower for firms that are faraway from innovators in terms of an index of productivity correlates. Indeed, our results imply that international spillovers can become negative with technological distance. At the same time, we find that the economic impact of technology transfer is, for most of the models, larger for the creation of new products than for the improvement of existing ones.

The literature has proposed several channels that could make knowledge spillovers negative. From a broader perspective, we can argue that existing knowledge can be a complement or a substitute for new knowledge. While in some cases knowledge itself can breed new innovations and entrepreneurship, the instruments in which knowledge is embedded can be exclusive. Additionally, these instruments or R&D activities might have market consequences that can undermine the generation of new knowledge.

The existence of negative international spillovers does not mean countries should close their global integration channels. In fact, we have little to say about the welfare effects of global spillovers. Indeed, for the case of patents the positive spillovers that emanate from the same geographic region can offset the negative spillovers from the rest of the world. Regarding international spillovers the data on quality and product innovation show that a significant share of firms faces negative international spillovers, however more productive firms do enjoy positive spillovers. These results notwithstanding, what the data robustly show is the importance of the national communication channels within countries and the learning mechanisms involved. It seems that firms and countries learn the most from those that are nearby, and thus some role for the public sector as a promoter of private sector innovation and entrepreneurship might be desirable.

The results presented also highlight the need to upgrade the knowledge production function used in endogenous growth models by allowing not just knowledge complementarities, but also substitution or competition effects. The evidence supports these considerations and highlights the need for new theoretical research that could investigate the growth and welfare implications of international knowledge spillovers. By the same token our results highlight the pertinence of studying different types of innovation as the nature of international knowledge spillovers could be different, depending on the type of innovation, be they product-quality upgrading, the introduction of new product varieties by firms, or patentable commercial inventions.

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8 Appendix

Table 1: Factor Loadings Corresponding to the Productivity Index

Variable	Factor 1-Loadings
dummy exporter	0.7812
dummy RD	0.1659
dummy Holding of licenses	0.1437
dummy Foreign ownership	0.6312
Log (workers)	0.8040

Note: This table displays the factor loadings corresponding to each of the variables included in the principal component analysis.

Table 2: R&D/GDP, Decade Average

	1963-1969	1970-1979	1980-1989	1990-1999	2000-2004
Japan	1.95%	2.45%	3.31%	3.72%	3.31%
USA	2.79%	2.25%	2.64%	2.58%	2.70%
Israel	1.03%	1.78%	3.08%	3.04%	4.71%
Singapore	0.08%	0.28%	0.79%	1.84%	2.24%
Australia	–	1.17%	1.42%	1.92%	1.83%
Republic of Korea	0.45%	0.64%	1.74%	3.07%	3.54%
New Zealand	–	1.14%	1.26%	1.38%	1.15%
China	–	–	0.71%	0.67%	1.22%
Scandinavia	1.43%	1.67%	2.43%	3.44%	3.16%
OECD	2.30%	2.19%	2.71%	2.74%	2.58%
EAP	0.44%	0.49%	1.01%	1.41%	1.27%
ECA	1.73%	1.44%	1.79%	1.16%	1.03%
MENA	0.04%	1.05%	0.40%	1.18%	0.90%
SHA	0.24%	0.27%	0.78%	0.82%	0.63%
SA	0.28%	0.42%	0.82%	0.69%	0.17%
LAC	0.47%	0.59%	0.35%	0.59%	0.65%

Source: Author's calculations based on data from Lederman y Saenz (2005) and UNESCO

Note: LAC: Latin America and the Caribbean; Scand.: Scandinavia, EAP: East Asia and the Pacific; ECA: Europe and Central Asia ; MENA: Middle East and North Africa (excluding Israel); SA: South Asia; SHA: Sub-Saharan Africa . All previous groups exclude high income countries..

Table 3: Per Capita R&D Expenditure (2000 US\$), Decade Average

	1963-1969	1970-1979	1980-1989	1990-1999	2000-2004
Japan	255.0	500.3	896.5	1319.7	1239.5
USA	467.8	458.1	655.3	778.6	949.0
Israel	71.6	191.1	401.9	493.0	836.1
Singapore	2.1	21.7	84.2	333.0	508.7
Australia	–	150.5	213.5	333.7	378.4
Republic of Korea	6.4	16.6	76.2	264.7	385.6
New Zealand	–	122.0	145.9	165.4	164.3
China	–	–	2.7	4.2	13.7
Scand.	194.7	276.7	527.4	835.0	941.0
OECD	220.0	288.8	426.1	445.6	533.5
EAP	13.0	14.1	38.8	94.8	49.3
ECA	32.6	35.5	62.7	31.1	40.7
MENA s/ISR	0.3	40.7	23.5	65.0	66.2
SHA	0.7	1.1	10.0	5.9	14.2
SA	0.6	1.1	2.8	2.9	1.0
L.A.C.	15.3	18.9	11.6	22.4	22.2

Source: Author's calculations based on Lederman y Saenz (2005) and UNESCO

Note: LAC: Latin America and the Caribbean; Scand.: Scandinavia, EAP: East Asia and the Pacific; ECA: Europe and Central Asia ; MENA: Middle East and North Africa (excluding Israel); SA: South Asia; SHA: Sub-Saharan Africa . All previous groups exclude high income countries..

Table 4: Patents, Yearly Average per Decade

	1963-1969	1970-1979	1980-1989	1990-1999	2000-2004
Japan	1147.4	5391.4	12240.2	23709.2	34048.6
USA	46856.9	46053.1	39359.4	60286.3	86362.2
Israel	39.4	80.4	179.7	450.1	1002.8
Singapore	0.6	3.0	6.6	64.7	360.0
Australia	113.7	220.8	339.8	498.4	858.6
Republic of Korea	1.3	6.8	52.2	1425.6	3802.0
New Zealand	13.6	25.9	49.6	62.1	129.6
China	4.6	6.9	13.9	57.1	260.8
Scandinavia	603.1	991.9	1068.0	1415.9	2617.8
OECD	2109.2	2432.0	2493.0	3847.4	5581.0
EAP	0.5	1.3	8.6	95.5	281.8
ECA	5.2	16.3	11.3	7.2	10.0
MENA	0.5	0.5	0.6	1.0	1.9
SHA	1.2	1.7	2.0	2.4	2.5
SA	1.2	1.8	1.3	5.1	28.4
LAC	76.7	91.0	86.0	161.7	258.4

Source: Author's calculations based on USPTO statistics.

Note: LAC: Latin America and the Caribbean; Scand.: Scandinavia, EAP: East Asia and the Pacific; ECA: Europe and Central Asia ; MENA: Middle East and North Africa (excluding Israel); SA: South Asia; SHA: Sub-Saharan Africa . All previous groups exclude high income countries..

Table 5: Product Innovation Rates by Region

Region	Quality-Innovations	Variety-Innovations
Sub-Saharan Africa	41%	52%
East Asia and Pacific	60%	39%
Europe & Central Asia	59%	43%
Latin America & Caribbean	33%	56%
Middle East and North Africa	36%	16%

Note: This table shows the composition of innovations per region across two dimensions: quality and variety innovations

Table 6: Product Innovation Rates by Industry

Industry	Quality-Innovations	Variety-Innovations
Textiles	43%	44%
Leather	72%	38%
Garments	45%	43%
Food	38%	51%
Beverage	67%	48%
Wood and Furniture	62%	49%
Non-metallic	47%	40%
Paper	43%	30%
Other manufactures	17%	50%
Auto and auto components	67%	45%
Other transports	78%	44%

Note: This table shows the share of firms reporting innovations by industry across two dimensions: quality and product variety innovations

Table 7: Summary Statistics: Quality upgrading and Creation of new goods

Variable	Observations	Mean	Std.Dev.	Min	Max
Domestic Knowledge Spillovers in quality	19305	64.994	84.398	0.000	413.000
Domestic Knowledge Spillovers in variety	19305	60.906	55.928	0.000	284.000
Foreign Knowledge Spillovers in quality (weighted by the inverse of distance between countries)	19229	1.277	2.960	0.000	32.788
Foreign Knowledge Spillovers in variety (weighted by the inverse of distance between countries)	19228	2.119	3.311	0.000	43.065
Index of Productivity	18850	-0.002	0.999	-1.694	4.242
Absolute distance between Index of Productivity and Average Productivity of the Innovators in quality	18850	0.757	0.506	0.000	3.797
Absolute distance between Index of Productivity and Average Productivity of the Innovators in variety	18850	0.770	0.514	0.000	3.904
Domestic Knowledge Spillovers in quality (weighted by distance in productivity)	18850	45.557	70.729	0.000	925.024
Domestic Knowledge Spillovers in variety (weighted by distance in productivity)	18850	43.644	50.173	0.000	606.593

Note: This table presents summary statistics of the main variables employed for the empirical analysis of firm product innovations.

Table 8: Cumulative Knowledge Production Function: Negative Binomial Estimations with Country Fixed Effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(log) SP country (t-1)	0.577	0.396	0.548	0.476	0.534	0.475	0.509	0.470
	[0.045]***	[0.045]***	[0.047]***	[0.049]***	[0.047]***	[0.048]***	[0.047]***	[0.048]***
(log) SP rest of the world (t-1)			-1.534					
			[2.261]					
Tertiary Enrollment Rate		1.478	0.957	2.354	0.543	0.701	1.419	1.510
		[0.319]***	[0.405]**	[0.398]***	[0.422]	[0.416]*	[0.476]***	[0.472]***
(log) SP Rest Income Group (t-1)				-0.168	0.383	0.31		
				[0.167]	[0.215]*	[0.213]		
(log) SP Rest of the World (Income Groups) (t-1)				-0.278	1.493	1.539		
				[0.190]	[0.503]***	[0.497]***		
(log) SP Rest of Geographic Group (t-1)							0.276	0.226
							[0.072]***	[0.072]***
(log) SP Rest of the World (Geographic Groups) (t-1)							-0.052	-0.065
							[0.143]	[0.142]
(log) Exports to the U.S.						0.163		0.133
						[0.037]***		[0.036]***
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	No	Yes	No	Yes	Yes	Yes	Yes
Observations	624	624	624	624	624	624	624	624
Pseudo R2	0.32	0.31	0.32	0.31	0.32	0.33	0.32	0.33
Over-dispersion	2236	2132	2242	2146	2250	2270	2260	2273
Over. p-val	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%.

SP= Stock of patents.

Table 9: Cumulative Knowledge Production Function with R&D Investment: Negative Binomial Estimations with Country Fixed Effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(9)	(10)	(11)
	Dependent Variable: Patent Counts during 5-year Periods									
SP country (t-1)	0.535 [0.042]***	0.665 [0.048]***	0.485 [0.050]***	0.593 [0.054]***	0.690 [0.050]***	0.613 [0.055]***	0.756 [0.053]***	0.476 [0.054]***	0.611 [0.047]***	0.628 [0.049]***
SP rest of the world (t-1)				-0.55 [0.132]***	1.999 [1.319]					
RD/GDP	0.463 [0.066]***	0.432 [0.054]***	0.431 [0.068]***	0.396 [0.066]***	0.441 [0.056]***	0.412 [0.066]***	0.451 [0.053]***	0.483 [0.066]***	0.492 [0.054]***	0.485 [0.054]***
Tertiary Enrollment			0.504 [0.266]*	1.248 [0.314]***	-0.188 [0.312]	1.231 [0.302]***	-0.175 [0.299]	1.36 [0.350]***	0.377 [0.309]	0.358 [0.308]
SP Rest Income Group (t-1)						0.088 [0.214]	3.206 [0.938]***			
SP Rest of the W. (Inc.) (t-1)						-0.556 [0.214]***	3.379 [1.139]***			
SP Rest Geo Group (t-1)								0.235 [0.075]***	0.283 [0.075]***	0.290 [0.075]***
SP Rest of the W. (Geo.) (t-1)								-0.341 [0.071]***	-0.335 [0.099]***	-0.346 [0.099]***
(log) Exports to the U.S.										-0.049 [0.048]
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	No	Yes	No	No	Yes	No	Yes	No	Yes	Yes
Observations	325	325	325	325	325	325	325	325	325	325
Pseudo R2	0.29	0.32	0.29	0.30	0.32	0.30	0.32	0.3	0.32	0.32
Over-dispersion	1382	1483	1386	1403	1485	1407	1494	1412	1518	1519
Over. p-val	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%.

SP= Stock of patents.

Table 10: Quality Upgrading (IQ) and New Goods (IV) : Estimation Results I

	Pr(IQ=1)	Pr(IQ=1 IV=1)	Pr(IQ=1,IV=0)	Pr(IQ=1,IV=1)	Pr(IV=1)	Pr(IV=1 IQ=1)	Pr(IQ=0,IV=1)	Pr(IQ=1,IV=1)
Know.spillovers	0.00326 [0.00064]***	0.00165 [0.00032]***	0.0016 [0.00033]***	0.00196 [0.00054]***	0.00202 [0.00055]***	0.00112 [0.00031]***	0.00083 [0.0018]***	0.00083 [0.00024]***
Distance to Innovators	-0.000243 [0.00035]	-0.00026 [0.00038]	-0.00012 [0.00018]	-0.00012 [0.00017]	-0.00001 [0.00033]	-0.00002 [0.00034]	-9.76E-06 [0.00019]	-7.24E-06 [0.00014]
*Know.spillovers	0.12837 [0.10445]	0.1394 [0.11356]	0.06509 [0.05317]	0.06327 [0.05133]	0.318221 [0.03774]***	0.32791 [0.04027]***	0.18272 [0.0241]***	0.13549 [0.01622]***
Distance to International Innovators	0.00026 [0.00079]	0.00028 [0.00086]	0.00013 [0.0004]	0.00013 [0.00039]	-0.00192 [0.00046]***	-0.00198 [0.00047]***	-0.00110 [0.00026]***	-0.00082 [0.0002]***
* International Know.spillovers								
Firm 's characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm s and Industry-Country' s characteristics	No	No	No	No	No	No	No	No
Country-Time fixed effects	No	No	No	No	No	No	No	No
Industry fixed effects	No	No	No	No	No	No	No	No
Num. of observations	17271	17271	17271	17271	17271	17271	17271	17271
Log pseudolikelihood	20200.75	20200.75	20200.75	20200.75	20200.75	20200.75	20200.75	20200.75

Note: This table presents the estimation results (marginal effects) of a bi-variate probit. One of the dependent variables is a dummy that takes value 1 if the firm reports quality up-grading. The other is a dummy that takes value 1 if the firm reports the introduction of new goods.

Table 11: Quality upgrading (IQ) and creation of new goods (IV) : Estimation Results II

	Pr(IQ=1)	Pr(IQ=1 IV=1)	Pr(IQ=1,IV=0)	Pr(IQ=1,IV=1)	Pr(IV=1)	Pr(IV=1 IQ=1)	Pr(IQ=0,IV=1)	Pr(IQ=1,IV=1)
Know.spillovers	0.000044	0.00010	7.49E-06	0.00003	8.10E-04	0.00052	0.00080	5.44E-06
Distance to Innovators	[0.00002]***	[0.0004]***	[0.0000]***	[0.00001]**	[0.00024]***	[0.00016]***	[0.00024]***	[0.0000]***
*Know.spillover	-0.000021	-0.00005	-3.52E-06	-1.00E-05	-0.00037	-0.00024	-0.00037	-2.49E-06
International Know.spillovers	[0.00001]***	[0.00002]***	[0.0000]***	[0.0001]***	[0.0001]***	[0.0001]**	[0.00016]**	[0.0000]***
	0.00294	0.00705	0.00049	0.00244	0.09474	0.06099	0.09411	0.00063
Distance to International Innovators	[0.0071]	[0.01701]	[0.0012]	[0.0059]	[0.04761]**	[0.03172]**	[0.04729]**	[0.00033]*
* International Know.spillovers	-0.00006	-0.00015	-0.00001	-0.00005	-0.00128	-0.00082	-0.00127	-8.57E-06
	[0.00005]	[0.00011]	[0.00001]	[0.00004]	[0.00029]***	[0.00021]***	[0.00028]***	[0.00000]***
Firm 's characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm 's and Industry-Country' s characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Num. of observations	17271	17271	17271	17271	17271	17271	17271	17271
Log pseudolikelihood	-16068.49	-16068.49	-16068.49	-16068.49	-16068.49	-16068.49	-16068.49	-16068.49

Note: This table presents the estimation results (marginal effects) of a bi-variate probit. One of the dependent variables is a dummy that takes value 1 if the firm reports quality up-grading. The other is a dummy that takes value 1 if the firm reports the introduction of new goods.

Table 12: Quality upgrading (IQ) and creation of new goods (IV) : Standardized marginal effects

	Pr(IQ=1)	Pr(IQ=1 IV=1)	Pr(IQ=1,IV=0)	Pr(IQ=1,IV=1)	Pr(IV=1)	Pr(IV=1 IQ=1)	Pr(IQ=0,IV=1)	Pr(IQ=1,IV=1)
Know.spillovers	0.3105	0.706	0.053	0.212	2.501	1.605	2.470	0.017
Distance to Innovators*Know.spillovers	-0.104	-0.247	-0.017	-0.049	-0.920	-0.597	-0.920	-0.006
International Know.spillovers					0.010	0.007	0.010	
Distance to International Innovators					-0.832	-0.533	-0.826	-0.006
* International Know.spillovers								

Note: This table presents standardized (by the standard deviation of the explanatory variables) marginal effects of a bi-variate probit. One of the dependent variables is a dummy that takes value 1 if the firm reports quality up-grading. The other is a dummy that takes value 1 if the firm reports the introduction of new goods. Results in bold are statistically significant at the 1% level, the other results are statistically significant at the 5% level. We do not report the marginal effects of non statistically significant results.