Universal Intellectual Property Rights: Too Much of a Good Thing?*

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Abstract

The paper studies developing countries' incentives to protect intellectual property rights (IPR). IPR enforcement is U-shaped in a country's market size relative to the aggregated market size of its trade partners: Small/poor countries enforce IPR to get access to advanced economies' markets, while large emerging countries free-ride on rich countries' technology to serve their internal demand. Asymmetric enforcement of IPR, strict in the North and lax in the South, often yields a higher level of innovation than universal enforcement. The empirical analysis conducted with panel data covering 122 countries and 45 years of world patents supports the theoretical predictions.

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1 Introduction

There has always been an international dimension to debates on intellectual property rights (IPR); with the integration of the world economy, however, IPR debates have become global. The United States, the European Union, Japan, and other developed countries, have actively lobbied to impose "Western-style" IPR legislation on every other country in the world. Contrary to the Paris and Berne Conventions, which allowed considerable flexibility in their application, the agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) imposes a common framework to all WTO members as regards IPR.[1] To date, this is the most important international agreement on the design of intellectual property regimes. And it is also the most controversial, having been challenged by many countries, including Korea, Brazil, Thailand, India and the Caribbean states. The present paper proposes a simple framework in which the desirability of enforcing IPR equally, everywhere, including in developing countries, can be assessed. The empirical relevance of the main theoretical results are tested with the help of panel data covering 122 countries and 45 years of world patents and discoveries.

The first source of conflict between developed and developing/emerging countries regarding the TRIPS agreement is that strong enforcement of IPR limits the possibility of technological learning through imitation, something which has been a key factor in the development of countries such as the US in the 19th century, Japan, Taiwan, or South Korea in the 20th century, and more recently China and India (see Sachs, 2003). Having copied technology invented by others, these countries have become major innovators: today the top three countries in term of R&D worldwide expenditure are the US, China, and Japan.[2]

The second source of conflict concerns medical drugs and, more generally, the fact that TRIPS does not stimulate research designed to benefit the poor, because the latter are unable to afford the high price of products

[1]The TRIPS agreement, negotiated through the 1986-94 Uruguay Round, is administered by the World Trade Organization and applies to all WTO members.

[2]See WIPO Publication No. 941E/2011 ISBN 978-92-805-2152-8 at www.wipo.int.

once they are developed. In 2001 this led to a round of talks resulting in the Doha Declaration, the aim of which is to ensure easier access to medicines by all. The declaration states that TRIPS should not prevent a country from addressing public health crises, and, in particular, that developing countries should be able to copy medicines for national usage when tackling such major issues as AIDS, malaria, tuberculosis or any other epidemics. They should also be able to import generic drugs if the domestic pharmaceutical industry cannot produce them. This declaration, which made a significant dent in the TRIPS agreement, has been challenged by the US and other developed countries with the help of organizations such as PhRMA (representing pharmaceutical companies in the US).

TRIPS was imposed without clear guidance from economic analysis. More studies are needed to illuminate the pros and cons of universal enforcement of IPR. The paper studies the impact of different IPR regimes on the investment decisions made by private firms in a two-countries model (developing and developed countries). We compare three IPR regimes: no protection; partial protection where only the rich country enforces IPR; and full protection where both countries enforce them. Since we want to study the impact of technology transfer on global innovation, we focus on incremental innovation: innovation enhances the quality of a vertically differentiated commodity, which is produced in each country by two firms (a domestic and a foreign) competing à la Cournot. This corresponds, for instance, to a new generation of mobile/smart phones, or an improvement of an existing drug. Indeed, most new products, especially drugs, are incremental improvements on existing ones (see CBO, 2006). The cost of the R&D investment depends on the efficiency of the R&D process, which by convention is higher in the advanced economy. By contrast, we assume that imitation is costless. However, it yields a potential indirect cost: a firm that violates IPR cannot export in a country that enforces them. Moreover, if one country does not enforce IPR, imitation occurs in both countries (i.e., both firms imitate). There are thus benefits for a country which enforces IPR in competing with a country that does not enforce them: it can freely copy its competitor's innovations, if any, even while IPR act as a barrier to its competitor entering into its market.

We show that the aggregated investment level is always higher under a partial protection regime than under a regime where there is no protection of IPR. One could argue that the 'no protection' regime is not relevant because rich countries do enforce IPR, so that, at worst, partial enforcement holds. This is true, however, only if illegal imports are banned. With smuggling the equilibrium converges towards the no-protection regime. This bad outcome militates for stricter enforcement of IPR, and helps to explain the lobbying by pharmaceutical companies and the music and movie industries. And in fact drugs, films and disks can easily be copied, smuggled or purchased over the Internet.[3]

This result seems to suggest that the greater the protection of IPR, the better it is for investment. Yet the link between protection of IPR and investment is not linear: full protection of IPR is not always conducive of a higher level of investment than a partial regime. Market integration with full patent protection guarantees the highest level of innovation in the asymmetric situation where only the rich country carries out R&D and when the developing country market is sizable. When both countries invest in R&D (e.g., China competing with the US), the total level of innovation is higher with partial protection. This result arises because, when technological transfer occurs, innovation by one firm expands the demand of the other firm so that it has more incentive to invest in R&D (i.e., the R&D investment of the two competing firms are strategic complements). Under a partial enforcement regime, an increase of investment by the firm in country 1 is matched by an increase in investment by the firm in country 2. This leads to higher market and demand growth, and hence welfare, than in the full protection regime. The optimal regime of IPR hence depends on the capacity of each country to do R&D and on the relative size of its internal market.

We next study the incentive that a developing country has to enforce

[3] "U.S. Customs estimates 10 million U.S. citizens bring in medications at land borders each year. An additional 2 million packages of pharmaceuticals arrive annually by international mail from Thailand, India, South Africa and other points. Still more packages come from online pharmacies in Canada" "Millions of Americans Look Outside U.S. for Drugs," Flaherty and Gaul, Washington Post, Thursday, October 23, 2003).

IPR, as required by TRIPS. Starting from the premise that rich countries have already adopted a strong level of protection, we show that a developing country will choose to respect IPR when its technological gap is large and its domestic market is small. For small developing countries it is indeed crucial to be able to export. Trade cooperation treaties and international conventions (culminated in the TRIPS agreement), require them to respect IPR to be allowed to serve foreign markets. By contrast, when the size of its national market is large compared to the foreign market, the developing country can afford not to protect IPR, even if this precludes its firms from legally exporting to a rich country (e.g., generic drugs produced without licence in India). This paper thus predicts that small developing countries should be willing to enforce IPR, while large emerging ones might be more reluctant to do so. From a static comparative point of view, an increase of foreign market access (which increases the relative importance of the size of foreign demand) increases the incentive to enforce IPR, since IPR protection enhances export opportunities.

Our analysis makes two main empirically testable predictions. The first is that the incentives to protect IPR in a developing country are decreasing in the relative size of its domestic market. This implies a U-shape relationship between patent protection and the relative size of a country's interior market: small developing countries and advanced economies strictly enforce IPR, while large developing countries are more reluctant to do so. Using a methodology developed in the new economic geography literature for measuring the foreign market potential, the empirical analysis confirms the existence of a U-shape relationship between patent protection and the relative size of a country's interior market vis à vis its trade partners.

The second set of predictions concern the impact of IPR enforcement on innovation. In our empirical analysis we distinguish between within-the-frontier innovations, which are a proxy for the intensity of technological transfer and reverse engineering, and on-the-frontier innovations, which measure genuine innovation. As expected, increasing IPR protection decreases within-the-frontier innovation. More interestingly, our model predicts that a stricter enforcement of IPR decreases genuine innovation by the local firm in the developing country, while increasing innovation by the firm in the developed country, without necessarily increasing innovation at the global level. Correcting for the endogeneity of IPR policy, the empirical results confirm that increasing IPR enforcement decreases on-the-frontier innovation of resident firms in developing countries, but increases innovation of nonresident firms, usually based in developed countries. The two effects cancel out when the two set of patents are merged, which supports the theoretical result that stronger enforcement of IPR in developing countries is not necessarily conducive to more R&D at the global level.

2 Related literature

Chin and Grossman (1991), Diwan and Rodrik (1991), Deardorff (1992) and Helpman (1993) were the first to study the effect of patent protection in an international context. These pioneering papers assume that only firms in the North can innovate. The harmonization of IPR amounts to introducing strong protection in the South to the benefit of Northern firms. Universal IPR is then conducive of more innovations (i.e., in the North), but it does not always enhance global welfare (e.g., due to monopoly distortions).[4] With the emergence of new players in R&D, such as India or China, it is important to extend the literature on IPR and trade to the case where all the countries can innovate. A first important paper here is Grossman and Lai (2004), which looks at two heterogeneous countries: one representing the North (high innovation, high demand) and the other the South (low innovation, low demand). In an economy in which consumers are characterized by Dixit-Stiglitz preferences and where innovation generates an increase in variety (i.e., horizontal innovation), the authors show that the South has a lower optimal level of protection. Moreover, patent policies are strategic substitutes so that the equilibrium level of patent

[4]A complementary empirical literature focuses on the impact of IPR protection in the South on exports by the North. Using OECD data, Maskus and Penubarti (1995) find that an increase in patent protection has a positive impact on bilateral manufacturing imports (i.e., the market expansion effect prevails over monopoly distortion). Similarly, Smith (1999), who studies US exports, shows that stronger IPR have a market expansion effect in countries with a strong capacity for imitation.

protection is inefficiently low. Efficiency can require increasing the level of protection in both countries, but harmonization (i.e., equal patent duration and enforcement rate) is neither necessary nor sufficient to achieve an efficient outcome. Starting from an equilibrium where, as in Grossman and Lai (2004), the optimal level of protection is smaller in the South, Lai and Qiu (2003) show that the South is also in general worse off if the policies are harmonized.

This literature focuses on uni-dimensional demand and/or technology ability: high for rich countries and low for poor countries. In this context, the optimal protection increases with the level of economic development.[5] The empirical literature thus explores the relevance of the positive relationship between patent protection and economic development as measured by GDP per capita. Maskus (2000), Braga, Fink, and Sepulveda (2000) and Chen and Puttitanun (2005) have empirically identified a *U-shape* relationship between IPR enforcement and per capita income, not a monotone one, showing the necessity of more theoretical work on this topic.[6]

Our model generalizes the existing literature in several directions. Compared to Chen and Puttitanun (2005), we study Northern firms' sensitivity to the choice of IPR in the developing country, as it has been shown to be a key determinant of their incentives to invest (see Chin and Grossman, 1991, Diwan and Rodrik, 1991, Deardorff, 1992 and Helpman, 1993). Second, we allow the developing country to export, because the South's willingness to respect IPR affects its ability to trade. Their willingness to enforce IPR is directly connected to their incentive to export. Finally, in our analysis, countries differ not only in per capita income but also in population size, which are both relevant demand characteristics. Because of the size of its population, the developing economy can be larger than the developed one, although poorer in per capita terms and generally endowed with less

[5] The North protects more because it is the main innovator and has the larger demand for innovative goods. Similarly, protection in the South generally increases when the size of the home market increases.

[6] As a first step, Chen and Puttitanun (2005) propose a two-sectors (import and domestic) model where the level of innovation in the rich country is fixed and firms in the poor country do not export. For some values of the parameters the level of protection first decreases and then increases when the per capita GDP of the country increases.

efficient R&D technology.

As in Scotchmer (2004), we rely on the relative size of the demand and on the technological gap between the two countries to conduct our static comparative analysis. Scotchmer (2004) provides separate analyses of the effect of asymmetries first in the size of the market (for the same innovative capability), and second in innovative capabilities (for the same size of the market). By looking at these simultaneously, we show that the relative size of the demand plays a crucial role in determining the willingness to enforce IPR, while the impact of the technological gap is of second order. In the theory below, large developing countries have generally a low incentive to protect IPR, while small poor ones always have strong incentives to respect them. This suggests a U-shape relation between IPR enforcement and relative demand intensity (i.e., own GDP compared to trade partners' GDP), which is confirmed by our data.

Another important point within the TRIP controversy concerns the impact of universal IPR enforcement on global innovation and on the ability of the South to develop high-tech industries and autonomous research capacity (see Sachs, 2003). So far, the literature on the effects of TRIPS on innovation has focused on the pharmaceutical industry. Using a product-level data set from India, Chaudhuri, Goldberg, and Jia (2006) estimate the demand and supply characteristics of a segment of the antibiotics market in India (quinolones). They then draw up counterfactual simulations of what prices, profits and consumer welfare would have been if the relevant molecular formulae had been under patent in India, as they were in the US at the time. Their results suggest that concerns about the potential adverse welfare effects of TRIPS are legitimate. Qian (2007) evaluates the effects of patent protection on pharmaceutical innovations for 26 countries that established pharmaceutical patent laws during 1978-2002. She shows that national patent protection alone does not stimulate domestic innovation, but that it does in countries with higher levels of economic development, educational attainment, and economic freedom. Kyle and McGahan (2012) test the hypothesis that, as a consequence of TRIPS, increased patent protection results in greater drug development efforts. They find that patent protection in high income countries is associated with increases in R&D effort, but that the introduction of patents in developing countries has not been followed by greater R&D investment in the diseases that are most prevalent there.

In this paper we extend this literature by looking at the impact of stricter IPR enforcement on innovation in other economic sectors. In the empirical application we show that stricter IPR protection can be detrimental to both inside-the-frontier (i.e., imitation-driven) and on-the-frontier innovations (as measured by patent activity) by Southern firms in the manufacturing sectors of a wide panel of countries. This gives credibility to the idea that by preventing technological transfers from the North, universal enforcement of IPR is limiting the development of Southern R&D activities in all sectors, and not solely in the pharmaceutical industry.

The remainder of the paper is structured as follows. Section 3 presents the base model, and robustness is checked in extension in the appendices. Section 4 derives the R&D investment levels equilibrium under different IPR regimes (i.e., none, partial, and full). The decomposition of the investments levels and the welfare analysis at the country level are conducted in section 5, which allows us to develop empirical predictions on the incentive the South has to invest in R&D and to enforce IPR. The empirical validity of the theoretical results is assessed in section 6. Section 7 concludes.

3 The model

We consider a two-country economy. There is one firm producing a vertically differentiated commodity in each country. We focus on quality augmented linear demand, which is derived from a quadratic utility function (see Appendix 8.1). Demand for good i in country j is written as:

$$p_{ij} = a_j(v_i - b_j(q_{1j} + q_{2j})) \quad i, j \in \{1, 2\} \tag{1}$$

where $a_j > 0$ and $b_j > 0$ are exogenous parameters, v_i represents the quality of good i, and q_{ij} is the quantity of good i sold in country j. It is easy to check that $p_{1j} - p_{2j} = (v_1 - v_2)a_j$ so that, unless goods are identical in quality, they are not perfect substitutes. As Goldberg (2010) points out for the pharmaceutical industry, even within narrowly specified therapeutic segments, consumers often have a choice of several alternative drugs, of varying levels of therapeutic effectiveness. The extent to which consumers are willing to pay more for higher-quality patented drugs may depend on several demand characteristics (see Chaudhuri, Goldberg, and Jia, 2006). In our model competitors sell two vertically differentiated qualities, and income differences across countries influence demands for the different qualities.

Countries differ in population size and per capita income. In the empirical application, a_j is interpreted as the per capita income and b_j as the *inverse* of the population size of country j (see Appendix 8.1). Then the parameter $\alpha_i = a_i/b_i$ corresponds to the GDP and reflects the intensity of the demand in country i, and $\alpha = \alpha_1 + \alpha_2$ is the depth of the global market. A parameter which plays an important role in the analysis below is the ratio

$$\gamma = \frac{\alpha_2}{\alpha_1} > 0. \tag{2}$$

The ratio γ captures the relative intensity of demand in country 2 with respect to demand in country 1. A small γ corresponds to a traditional North-South trade relationship, where the developing country is poor (i.e., has a small GDP) such that its internal market is small compared to the internal market of the advanced economy. A large γ signals that the developing country market is important for the advanced economy. It corresponds to the new trade relationships as between fast-emerging countries such as China, India or Brazil, and advanced economies. To study the impact of technological transfers on global R&D we focus on incremental innovation: starting from a common level of quality before investment equal to 1, vertical innovation increases the quality of the commodity by ϕ_i. As in Sutton (1991, 1997), this corresponds to a quality-enhancing innovation which shifts the linear demand upwards (i.e., a new and more effective drug, a new generation of mobile phones, etc.).[7] The cost of the R&D investment is $k_i\frac{\phi_i^2}{2}$, where $k_i > 0$ is an inverse measure of the effi-

[7] This marks a difference from Grossman and Lai (2004) and Lai and Qiu (2003), where innovation is not cumulative (see also the discussion in section 4.2).

ciency of the R&D process in country $i = 1, 2$. By investing $k_i \frac{\phi_i^2}{2}$ a firm increases the quality of the good from $v_i = 1$ to $v_i = 1 + \phi_i$. Innovation is thus deterministic.[8] Without any loss of generality we assume that firm 1, based in country 1, has the most efficient R&D process (i.e., country 1 is the advanced economy).

$$\Delta = \frac{k_2}{k_1} \geq 1 \tag{3}$$

The ratio $\Delta \geq 1$, which measures the technological gap between the two countries, plays an important role in the analysis below. With $\gamma > 0$ defined above, these are the two main comparative static parameters of the paper.

3.1 IPR regimes

The firms play a sequential game. In the first stage, they invest in R&D. In the second stage, they compete in quantities (a Cournot game). To keep the exposition simple, we assume that, once an innovation is developed, the production costs are zero.[9] In the first stage they might choose to copy their competitor innovation, or not. If imitation occurs it is perfect. Because of this potential free-rider problem, the level of protection of the innovation influences investment in R&D. We distinguish three intellectual property rights (IPR) regimes, denoted $r = F, N, P$:

1. Full patent protection (F): both countries protect patents and the quality after investment of the good produced by firm i is $v_i^F = 1+\phi_i$.

2. No protection (N): countries do not protect patents and the quality after investment of the good produced by firm i is $v_i^N = 1 + \phi_i + \phi_j$.

3. Partial protection (P): only country 1 (i.e., the rich country) protects innovation. If firm 2 violates the patent rights of firm 1, it will not be

[8] Our focus is on the incentive to invest in R&D so this assumption simplifies the exposition. If innovation was stochastic so that the probability of improving the quality was increasing with the amount invested, the same qualitative results would hold.

[9] Instead of setting marginal production costs to zero, we could define p_i as the price net of marginal cost of firm i. In this case, an increase in the intercept parameter $a_i v_i$, for the same level of income a_i, could be both interpreted as an increase in quality v_i or a decrease in the marginal production cost. This alternative model gives similar qualitative results (computations available upon request).

able to sell its product in country 1. Moreover, since country 2 does not enforce IPR, firm 1 can reproduce the incremental technological improvement developed by firm 2, if any, so that $v_i^P = v_i^N = 1+\phi_i+\phi_j$.

If both countries enforce IPR (regime F), imitation is not allowed and each firm privately exploits the benefits of its R&D activity. If one or both countries do not enforce IPR (regime N or P), imitation occurs in *both* countries (i.e., *both* firms imitate). In the case of imitation, innovations are assumed to be cumulative. Each firm imitates its rival's innovation and improves upon it through its own R&D activity.

Since our focus is upon the innovative activity, we do not detail how firms serve the demand in the foreign market. In open economies firms can choose a variety of arrangements to minimize the sum of production and transportation costs. Once an innovation is made a firm may choose to serve a foreign market by exports, by foreign direct investment (FDI) or, under regime F, by licensing its intellectual asset to a foreign firm through a production-licensing agreement. In our base model, this choice of production allocation is a black box and the related costs are normalized to zero.[10]

3.2 Choice of quantities

Differences between N and P arise after the investment phase: in the partial regime (P), country 1, which strictly enforces IPR, forbids imports by the imitator, and firm 1 is thus in a monopoly position at home. That is, $q_{21}^P = 0$ and $q_{11}^P = q_1^M = \frac{v_1^P}{2b_1}$.

In all regimes $r = F, N, P$, firms in country 2 are in a duopoly configuration. For a given quality vector (v_1^r, v_2^r), the firm i maximizes its profit, $\Pi_i^r = p_{i1}^r q_{i1} + p_{i2}^r q_{i2} (-k_i \frac{\phi_i^2}{2})$ where p_{ij}^r is the price defined in equation (1) when the quality is v_i^r. The cost of R&D is in brackets because it has been sunk in the first stage. It is straightforward to check that the profit

[10]Appendix 8.2 shows that our results are robust to the existence of export costs. Different levels of IPR protection also affect the choice among licensing, FDI, and trade. However the existing empirical evidence is inconclusive on the impact of IPR on this choice (see Fink and Maskus, 2005).

is concave in q_{ij}. The first-order conditions are sufficient. At the second stage of the production game, the quantity produced by firm i for country j is the Cournot quantity $q_{ij}^r = \frac{2v_i^r - v_{-i}^r}{3b_j}$, where the index $-i \neq i$ represents the competitor and the value of v_i^r depends on the IPR regime, i.e., $v_i^r \in \{v_i^F, v_i^N, v_i^P\}$.

We deduce that the quantities produced at the second stage of the game are:

$$q_{ij}^r = \begin{cases} \frac{v_1^P}{2b_1} & \text{if } i = j = 1 \text{ and } r = P \\ 0 & \text{if } i = 2,\ j = 1 \text{ and } r = P \\ \frac{2v_i^r - v_{-i}^r}{3b_j} & \text{otherwise} \end{cases} \tag{4}$$

The profit of firm $i = 1, 2$ is then written as:

$$\Pi_i^r = p_{i1}^r q_{i1}^r + p_{i2}^r q_{i2}^r - k_i \frac{\phi_i^2}{2} \tag{5}$$

where p_{ij}^r is the function defined in equation (1) evaluated at the quantities defined in (4) and quality vector (v_1^r, v_2^r) is given by $v_i^P = v_i^N = 1 + \phi_i + \phi_j$ and $v_i^F = 1 + \phi_i$ $i, j = 1, 2$.

4 Investment in R&D

As a benchmark case we first compute the optimal investment level from a global social point of view when the production levels are defined by (4). The welfare of country $j = 1, 2$ is $W_j^r = S_j^r + \Pi_j^r$ where Π_j^r is defined in equation (5) and

$$S_j^r = a_j(v_1 q_{1j}^r + v_2 q_{2j}^r) - a_j b_j \frac{(q_{1j}^r + q_{2j}^r)^2}{2} - p_{1j}^r q_{1j}^r - p_{2j}^r q_{2j}^r \tag{6}$$

with q_{ij}^r defined equation (4). The optimal investments ϕ_1 and ϕ_2 are the levels chosen by a centralized authority maximizing total welfare:

$$W = W_1^r + W_2^r. \tag{7}$$

A supranational social planner always chooses full disclosure of innovation (i.e., the no-protection regime N). Once the costs of R&D have been sunk, she has no reason to limit innovation diffusion. At the optimum, $v_1^* = v_2^* = 1 + \phi_1 + \phi_2$. Substituting these values in (5) and (6), the socially optimal level of innovation in country i is obtained by maximizing W with respect to ϕ_1 and ϕ_2. Recall that $\alpha = \alpha_1 + \alpha_2$. This yields, for $i = 1, 2$, $\phi_i^* = \frac{\alpha(1+\Delta)}{\frac{9}{8}\Delta k_1 - \alpha(1+\Delta)} \frac{k_j}{(1+\Delta)k_1}$, which is defined only if $k_1 > \frac{8}{9}\frac{1+\Delta}{\Delta}\alpha$.[11] A necessary condition to obtain interior solutions in all cases (i.e., for all $\Delta \geq 1$) is that k_1 is larger than $\frac{16}{9}\alpha$. To be able to characterize the optimal levels of investment, and to warrant that our different maximization problems are concave, we thus make the following assumption.

Assumption 1 $$k_1 = 2\alpha$$

Since we are interested in the role of IPR on innovation activities, we concentrate on relatively small k_1 (i.e., k_1 is close to the threshold value $\frac{16}{9}\alpha$), for which innovation in country 1 matters. We fix k_1 equal to 2α for ease of notation. This normalisation is not crucial for our results (see appendix 9.1). What matters for our static comparative results is that Δ, the technological gap between the two country, varies. Under assumption 1 the optimal level of investment, $\phi^* = \phi_1^* + \phi_2^*$, is:

$$\phi^* = \frac{4(\Delta + 1)}{5\Delta - 4}. \tag{8}$$

It thus decreases with $\Delta \geq 1$, the efficiency gap between countries 2 and 1, which is an intuitive result.

We next turn to the more realistic case where countries compete in R&D. At the second stage, quantities are given by the levels in (4). At the first stage (investment stage), firm i maximizes the profit (5) with respect to ϕ_i, for a given level of ϕ_j, $i \neq j$. The level of innovation available to firm i depends on the enforcement of IPR. Details of the computations of the different cases is given in Appendix 8.2.

Full IPR protection (F regime): In the case of universal IPR protection, firms cannot free-ride on each other's innovation. The quality of good i depends solely on firm i's investment: $\phi_i^F = \phi_i$. Solving the system of first-order conditions of profit maximization, we obtain that $\phi_i^F = \frac{3\frac{k_j}{\alpha} - 4}{15\Delta - 8}$.

[11] If $k_1 \leq \frac{8}{9}\frac{1+\Delta}{\Delta}\alpha$ the optimal level of investments are unbounded.

Since by convention $k_2 = \Delta k_1 \geq k_1$, the highest quality available to consumers in this setting is $\phi^F = \phi_1^F$, which under assumption 1 is:

$$\phi^F = \frac{6\Delta - 4}{15\Delta - 8} \tag{9}$$

No IPR protection (N regime): When IPR are not protected, firms can imitate the innovations of their competitors. The quality of good i after investment is given by $1 + \phi^N = 1 + \phi_1^N + \phi_2^N$. Solving for the equilibrium (i.e., the intersection of the reaction functions) we have: $\phi_i^N = \frac{1}{8\Delta - 1}\frac{k_j}{2\alpha}$. Since $\phi^N = \phi_1^N + \phi_2^N$ we deduce that under assumption 1:

$$\phi^N = \frac{\Delta + 1}{8\Delta - 1}. \tag{10}$$

Asymmetric IPR protection (P regime): When only country 1 protects IPR, firms can imitate their competitors' innovation. The quality of good $i = 1, 2$ after investment is given by $\phi^P = \phi_1^P + \phi_2^P$. Moreover, both firms can sell in the market of country 2, but imitated goods cannot be exported in 1. Then if firm 2 chooses imitation, firm 1 has a monopoly in country 1, and it competes with firm 2 à la Cournot in country 2. In equilibrium the total level of investment $\phi^P = \phi_1^P + \phi_2^P$ is :

$$\phi^P = \frac{9\Delta + 4\gamma(1 + \Delta)}{27\Delta + 4\gamma(8\Delta - 1)} \tag{11}$$

Under the P regime, when firm 2 free-rides on innovation by firm 1 it cannot export in country 1. This restriction breaks the symmetry between the two markets. The total innovation level ϕ^P decreases with γ, the relative size of country 2. The reason for this is that when the market in country 2 becomes relatively more sizeable compared to the market in country 1, the negative impact of free riding on innovation by firm 2 becomes more important, decreasing the total level of investment.

4.1 Comparison of investment levels

Comparing (8), (10), and (11) it is easy to check that $\phi^* > \phi^P > \phi^N$ for all $\Delta \geq 1$. The levels of investments with either no protection or partial protection of IPR are suboptimal compared with the optimal level (8).

This result is hardly surprising. The incentives of the firms are wrong (i.e., they focus on profit) and the free-rider problem takes its toll on R&D investment when their property rights are not well enough protected. More interestingly, the aggregated investment level is always higher under a partial protection regime than under no protection at all. This result gives credibility to the idea that better protection of property rights is conducive to more innovation at the global level. The next result shows the limits of this intuition.

Proposition 1 *There is a threshold* $\Delta(\gamma) \in (1, \frac{4}{3})$ *decreasing in* $\gamma \geq 0$ *such that:*

- *If* $\Delta \leq \Delta(\gamma)$ *then* $\phi^N \leq \phi^F \leq \phi^P \leq \phi^*$
- *If* $\Delta > \Delta(\gamma)$ *then* $\phi^N \leq \phi^P < \phi^F \leq \phi^*$.

Proof. See appendix 8.2. ■

Contrary to what the proponent of strong IPR enforcement argues, it is not always true that stronger enforcement of IPR increases global investment. The result very much depends on the capacity of each country to do R&D. When copying is not allowed (i.e., in regime F), the firms' investments are strategic substitutes and the maximum level of investment committed by firm 1 increases when Δ, the relative efficiency of firm 1, increases. Two cases are particularly relevant from an empirical perspective.

First, the innovation activity of many developing countries is still negligible. Innovative activities are concentrated in a handful of countries, with the top seven countries accounting for 71 % of the total R&D worldwide expenses.[12] When only the advanced economy (by convention, country 1) invests in R&D, corresponding in our model to $\Delta \to \infty$, the second condition of Proposition 1 holds and market integration without strong IPR yields a low level of investment compared to stronger IPR regimes. By continuity market integration with full patent protection F guarantees the highest level of innovation whenever the two countries have very unequal technological capacity.

[12] These countries are the US, China, Japan, Germany, France, the UK and South Korea. See WIPO Publication No. 941E/2011 ISBN 978-92-805-2152-8 at www.wipo.int

Second, as emerging countries such as China or India have developed world-class level R&D systems, we need to consider the case where country 2 is able to decrease its technological gap. When Δ is small, global innovation is higher if country 2 does not protect IPR (i.e., in the P regime). This result arises because, when copying is possible (i.e., in cases $*$, P and N), the firms' investments are strategic complements so that the total level of investment decreases with $\Delta \geq 1$. In the Nash equilibrium played by the two firms, the level invested by the competitor is perceived as exogenous. It is a demand booster which stimulates market growth when it can be copied. An increase of investment by a firm in country 1 is hence matched by an increase in investment by a firm in country 2. Thanks to the appearance of new generations of products and/or new applications (e.g., smart phones), the demand expands so that the firms have more incentive to invest in quality development. Therefore the total level of innovation is higher (i.e., it is closer to the first best level) under a partial protection system P than under a full protection system F.[13] This equilibrium does not militate for universal enforcement of IPR.

Third, the threshold value at which the innovation level under F becomes larger than the innovation level under P, $\Delta(\gamma)$, increases when the size of the interior market of country 1 rises compared to the interior market of country 2 (i.e., it decreases with the ratio γ). Intuitively, for a given size of the total market α (i.e., total GDP), when the relative size of market 2 is small, the free-riding problem becomes less important. Firm 2 can only sell in country 2, a small market, and the investment in R&D is less harmed by partial protection of IPR. On the contrary, if market 2 is large, free-riding by firm 2 has a stronger effect on the total incentive to innovate. In other words, when small poor countries free ride on investment by rich countries, they have a smaller impact on the total incentives to innovate than when large poor countries free ride.

We have shown that total investment in R&D is often higher under regime P than under regime F. In appendix 8.6 we also show that the

[13] In the limit, the investment in F converges towards the low level of N: $\lim_{\Delta \to 1} \phi^F = \phi^N$. Imitation then does not reduce the quality of the product available in the two markets but reduces the total investment costs (they are not duplicated).

asymmetric IPR regime P is often the globally optimal (utilitarian) policy.

4.2 Discussion and robustness

While this account of the model is straightforward and the results intuitive, it glosses over several simplifying assumptions. In this section we discuss the robustness of the result of Proposition 1 with regard to these assumptions.

In our model the production and transportation choices are a black box, and the related costs are normalized to zero in both countries. Yet there might be specific costs associated to serving a foreign market. In appendix 8.2 we assume that selling in a foreign country implies a unit cost equal to $t \geq 0$ (e.g., an exportation cost). We show that the result of Proposition 1 still holds for values of $t > 0$ which are not too large (for very large values of t there is no trade, so IPR regimes do not matter for investment).

Assumption 1 fixes k at a relatively low level so that in equilibrium investment in R&D is substantial (because it is not too costly) and country 2 has an incentive to free ride on innovation produced by firm 1. Appendix 9.1 shows that the particular level of k is not crucial for the results. For other values of k which are not too big, the investment levels and welfare have the same shape as in the base case and only the value of the relevant thresholds are modified. By contrast, when k becomes very large the innovation levels decrease drastically under all regimes and country 2's incentive to imitate decreases accordingly.

The assumption of cumulative innovation in case of imitation (regimes P and N), $v_i^N = v_i^P = 1+\phi_i+\phi_j$, is realistic in many industries and is a good match to the process of technological transfer at the heart of the TRIPS controversy, and which is the focus of this study. Nevertheless, in some cases innovation is not cumulative. In appendix 9.2 we check the alternative hypothesis that, under imitation, the quality available is the best innovation of the two firms: $v_i^N = v_i^P = 1 + \max\{\phi_i, \phi_j\}$. It turns out that this assumption is equivalent in our base model to the limit case where $\Delta \to \infty$. With non-cumulative innovation, Proposition 1 then implies that a strict enforcement of IPR is conducive at the global level to more innovation than a partial regime, an intuitive result when only the maximum of the two investments matters. This is also consistent with Grossman and Lai (2004) and Lai and Qiu (2003). In their models innovation is not cumulative, so that an increase in the strength of protection always increases innovation.

When considering the IPR regimes in case of copying by firm 2, we have restricted our attention to the limit cases of either perfect enforcement in country 1 (regime P) or no enforcement (regime N). However, firm 2 might be able to smuggle some of its production into country 1. We explore the possibility of illegal imports in appendix 9.3, by assuming that if firm 2 copies firm 1's innovation, firm 2 can only sell in country 1 an expected quantity of $q_{21}^f = (1-f)q_{21}^o$, where q_{21}^o represents the Cournot quantity and $f \in [0,1]$ the quality of enforcement in country 1. If $f = 1$, we are in the former regime P and firm 2 cannot export in 1: $q_{21}^f = q_{21}^P = 0$. If $f = 0$ there is no restriction to imports of imitated goods in country 1, and we are in regime N: $q_{21}^f = q_{21}^N = \frac{1+\phi_1^N+\phi_2^N}{3b_2}$. Imperfect enforcement corresponds to an intermediate case between N and P so that in equilibrium: $\phi^N \leq \phi^f \leq \phi^P$ for $f \in [0,1]$. We deduce from Proposition 1 that illegal imports tend to reduce the incentive to innovate at the global level, which is consistent with the result obtained in the literature on *legal* parallel imports (see Malueg and Schwartz, 1994, Rey, 2003, Valletti, 2006, Li and Maskus, 2006).[14]

In our base model, when the firms imitate, they can fully incorporate the innovation developed by their rival. Appendix 9.4 explores the case of imperfect imitation by assuming that $v_i^N = v_i^P = 1 + \phi_i + g\phi_j$, with $0 \leq g \leq 1$. The base case model is obtained for $g = 1$ so that, when g is sufficiently close to 1, our results are preserved. More generally, for $g > 1/2$, the investment levels are strategic complements and the reaction functions are qualitatively similar to the ones in the base case. Our main results hold but the relevant thresholds change: regimes (P) and (N) are preferred more often from the total welfare point of view. This is in line

[14] Illegal imports are different from parallel imports (or international exhaustion), which are legal. Yet by reducing the possibility of performing price discrimination by Northern firms, parallel imports also weaken their incentives to innovate (see Malueg and Schwartz, 1994, Rey, 2003, Valletti, 2006, Li and Maskus, 2006). This result is partially challenged by Grossman and Edwin (2008) and Valletti and Szymanski (2006).

with several empirical studies which find that, when the imitation capacity is lower, the negative impact of weak IPR on imports is less pronounced or disappears (see Fink and Maskus, 2005).

5 Empirical implications

5.1 IPR enforcement

The result of Proposition 1 is at the aggregate (world) level. To conduct the empirical analysis we need to derive results at the country level. Moreover the result of Proposition 1 is based on a comparison of all hypothetical regimes. Yet in practice advanced economies are already enforcing IPR, while developing/emerging countries are not necessarily protecting them. Starting from the premise that country 1 (the advanced economy) has a strong IPR regime, the relevant policy question is when country 2 (the developing country) will choose to enforce IPR as well. Taking the IPR regime of country 1 as given, country 2 chooses the protection regime F or P which yields the highest national welfare.

Proposition 2 *There are two thresholds* $0 < \underline{\gamma} < \overline{\gamma}$ *such that:*

- *If* $0 < \gamma < \underline{\gamma}$ *then* $W_2^F > W_2^P$*;*
- *If* $\underline{\gamma} \leq \gamma \leq \overline{\gamma}$ *then there exists a threshold value* $\Delta_2(\gamma) \geq 1$ *such that* $W_2^F \geq W_2^P$ *if and only if* $\Delta \leq \Delta_2(\gamma)$*;*
- *If* $\gamma > \overline{\gamma}$ *then* $W_2^F < W_2^P$*.*

Proof. See Appendix 8.3. ■

Country 2 chooses to enforce IPR when its domestic market is relatively small (i.e., when γ is small). In this case it is very important for country 2 to have access to the market of country 1. This can happen only if country 2 respects IPR. It thus adopts F to be able to trade freely with country 1. By contrast, when the size of its national market is relatively large, country 2 can afford not to protect IPR, even if this precludes firm 2 from legally exporting in country 1. This helps to explain why fast-emerging countries, such as China, have been reluctant to enforce IPR as their huge domestic markets developed. The vast majority of Chinese manufacturing firms produce only for the Chinese internal market. Less than a third (26.3% according to Wakasugi and Zhang, 2012 and 30.2% according to Lu et al., 2010) of Chinese manufacturing firms actually export, with considerable heterogeneity between domestic firms (only 15.7%-20% are exporting something) and foreign-owned ones (60.8%-64.1% are exporters).

From an empirical point of view, we expect the degree of enforcement of IPR to be U-shaped in α_i, the country market intensity (i.e., total GDP and not solely per capita GDP), and inversely U-shaped in α_j, the intensity of its export market. Concretely, poor countries with a small interior market will tend to enforce IPR more strictly. Symmetrically, rich advanced economies are, for historical reasons, also strictly enforcing IPR. In the middle, emerging countries with large populations will tend to free ride on rich countries' innovations by adopting a weak enforcement of IPR.

5.2 Conflicts over IPR enforcement

For country 1, it is not clear that the choice of not protecting IPR in country 2 is necessarily bad. If IPR are effectively respected in country 1, when country 2 chooses to steal the technology developed in country 1, this reduces competition in country 1. At the same time, if firm 2 also innovates and IPR are not protected in 2, firm 1 can include the innovations developed by its competitor in its own products. Incremental innovations made by firm 2 increase the stock of innovation offered by firm 1, in turn increasing the demand for its products and thus its profit. The next result establishes that the position of the advanced economy vis à vis IPR adoption by its trade partner is indeed sometimes ambiguous.

Proposition 3 *There is a threshold $\gamma_1 > 0$ such that:*

- *If $\gamma < \gamma_1$ then $W_1^P > W_1^F$;*
- *If $\gamma \geq \gamma_1$ then there exists a threshold value $\Delta_1(\gamma)$ increasing in γ such that $W_1^F \geq W_1^P$ if and only if $\Delta \geq \Delta_1(\gamma)$.*

Proof. See Appendix 8.4. ■

Figure 1 illustrates the results of Propositions 2 and 3 by representing the welfare gains/losses obtained by country i when the regime shifts from P to F (i.e., the sign of $W_i^F - W_i^P$). There is no conflict between the two countries in the white region only. This result helps to explain why it is so hard to find a consensus on agreements such as TRIPS. The interests of developing countries and of advanced economies are generally antagonistic.

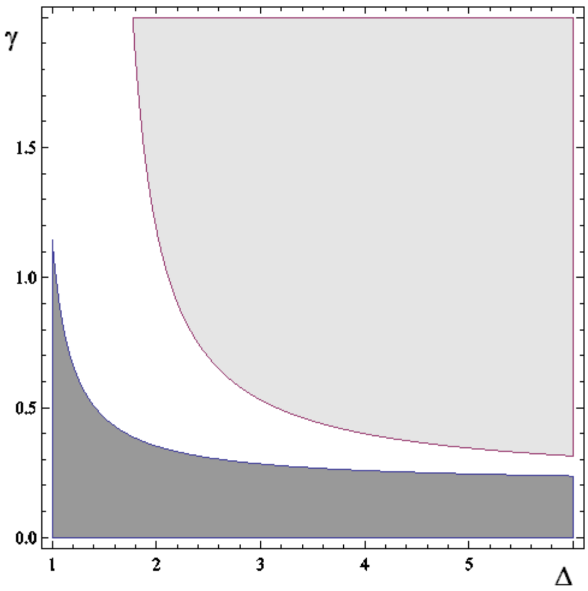

Figure 1: Welfare difference $W_i^F - W_i^P$. In the dark shaded region $W_2^F - W_2^P > 0$ and in the light shaded region $W_1^F - W_1^P > 0$.

Contrary to the developing country, country 1 prefers regime P whenever γ or Δ are small enough. It prefers full enforcement F otherwise (see Appendix 8.6 for more details). For intermediate values of γ, when country 2 is very inefficient (large Δ), it chooses not to protect IPR and to free ride on country 1's innovations by choosing regime P, while country 1 would prefer F. However, as Δ decreases the developing country switches to regime F, while country 1 would prefer to protect its interior market from imports with P. Concretely, the incentives to enforce IPR more strictly will rise as an emerging country moves from zero to substantial investment levels in R&D. This dynamic is illustrated by the Indian pharmaceutical industry. For decades, India has produced drugs without respecting IPR, initially to serve its interior market, but later to serve other developing countries. The share of pharmaceuticals in national exports has hence increased from 0.55 per cent in 1970-71 to over 4 per cent by 1999/2000 (see Kumar, 2002). This led Western pharmaceutical companies to lobby for a strict enforcement of IPR at the world level and, eventually, to the TRIPS agreement. However, now that India has developed a full-fledged pharmaceutical industry and built R&D capacity, it has changed its legislation. As a result of the 2005 patent legislation, Indian drug firms can no longer copy medicines with foreign patents.[15]

5.3 IPR and innovation in poor countries

We decompose the result of Proposition 1 at the country level to assess the impact of enforcement of IPR on innovative activities in the South and in the North. In the base model it is assumed that before investment the two firms have the same quality, normalized to 1. However, in real-world situations, the qualities of innovations produced by the two firms differ ex-ante (i.e., before investment). Appendix 8.5 proposes an extension of the model where, before investment, the quality of firm 1 is $v_1 = 1$ and the quality of firm 2 is $v_2 = 1 - d$, with $d \in [0, 1]$ representing the gap between the two goods. If imitation occurs, this gap can be closed and everything is as in the base case. The difference between the two variations of the model is thus under regime F, where the quality of firm 2 after innovation is $v_2^F = 1 - d + \phi_2^F$, while the quality of firm 2 is $v_1^F = 1 + \phi_1^F$.

Proposition 4 *Let ϕ_{id}^F be the level of investment by firm $i = 1, 2$ when $d \in [0, 1]$. We have that $\phi_{2d}^F \leq \phi^P$ $\forall d \in [0, 1]$. Moreover, there exist $\tilde{d} < \hat{d} \leq \frac{1}{4}$ such that*

- $\phi_{1d}^F \geq \phi_1^P \Leftrightarrow d \geq \tilde{d}$
- $\phi_{2d}^F \leq \phi_2^P \Leftrightarrow d \geq \hat{d}$

[15] Prior to 2005, Indian drug producers could copy patented medicines of foreign firms to create generic by means of reverse engineering. This measure was introduced in the seventies to offer affordable medicines to the population, which was unable to buy foreign drugs. This policy of piracy boosted the Indian pharmaceutical sector, making it able to address local market needs with surpluses that facilitated exports.

Proof. For proof, see Appendix 8.5. ■

In the appendix we show that when either $\gamma \geq 1/3$ or $\Delta \geq 4/3$, $\tilde{d}$ is strictly negative, which implies that the first condition of Proposition 4 always holds and ϕ_{d1}^F is always larger than ϕ_1^P. Since most developing countries are either doing no R&D (i.e., $\Delta \to +\infty$) or, when they are doing substantial R&D such as India or China, they have a very large internal market (i.e., γ is large), we predict an increase in innovation activities of the firm in the advanced economy when IPR are better enforced in the developing country. Proposition 4 also implies that the impact of enforcing IPR more strictly tends to have the opposite effect on innovation activities in the advanced economy and in the developing one. Indeed, the impact of a stricter policy is the same only when $d \in (\tilde{d}, \hat{d})$, which is a narrow range (i.e., $\hat{d} \leq 0.25$). We hence predict that when IPR are better enforced in a developing country, genuine innovation by local firms should decrease. Finally, independently of its R&D investment effort, the level of quality produced by the firm in the developing country is always higher under regime P than under regime F (i.e., $\phi^P \geq \phi_2^F \geq \phi_{2d}^F \; \forall d \in [0, 1]$).

6 Empirical analysis

6.1 The data

To empirically test the two main predictions of the model, we use several data sources. The data on IPR protection are drawn from Park (2008), who updates the index of patent protection published in Ginarte and Park (1997). The original paper presented the index for 1960-1990 for 110 countries. The index has now been updated to 2005 and extended to 122 countries (it is calculated in periods of 5 years).

Trade data is based on COMTRADE, from the United Nations Statistical Department. Although this source contains data from the 1960s to the present, more accurate information is derived from the new release of TradeProd, a cross-country dataset developed at CEPII.[16] This source

[16] In particular, this dataset takes advantage of mirror flows (reports for both exporting and importing countries) to improve the coverage and quality of trade flows

integrates information from COMTRADE and OECD-STAN and covers the period 1980–2006. A detailed description of the original sources and procedures is available in De Sousa, Mayer, and Zignago (2012).

For measuring innovation, following Klinger and Lederman (2009, 2011) we distinguish between "inside-the-frontier" innovation and "on-the-frontier" innovation. This distinction is important because in the case of partial enforcement (P), both imitation and incremental innovation take place and not all innovations are patented (because imitating firms cannot patent their innovation). Klinger and Lederman (2009, 2011) propose export discoveries, i.e., the discovery of products for exports that have been invented abroad but that are new to the country, as a measure of "inside-the-frontier" innovations.[17] This is measured by the number of new products that enter a country's export basket in any given year, calculated using trade data from COMTRADE and BACI-CEPII (for more details on the construction of the variable, see Appendix 10.3).

"On-the-frontier" innovation is defined as the invention of products that are new not only to the country but also internationally. We measure it by the number of patent applications from domestic and foreign firms resident in a country, and it is provided by the World Bank (World Development Indicators).

We also employ information on cross-country human capital levels from Barro and Lee (2010). This widely used dataset reports levels of education attainment in periods of 5 years. All other data are from the OECD and the World Bank.

6.2 Empirical results

Our model predicts that developing countries with a relatively small internal market compared to their trade partners prefer to enforce patent rights, while those with a larger internal market become less willing to strictly en-

at a very disaggregated product level. TradeProd is available from the CEPII website (http://www.cepii.fr)

[17]The use of export discoveries as a measure of "inside-the-frontier" innovation is inspired by the work of Imbs and Wacziarg (2003). These authors show that economic development is associated with increasing diversification of employment and production across industries rather than specialization.

force IPR. Since developed countries are already protecting IPR, the first empirical implication of the model is that patent enforcement is a U-shape function of the relative size of the internal market (i.e., the relative importance of domestic sales with respect to exports). We thus expect patent enforcement to be a U-shape function of the size of the national market and an inverted U-shape function of the size of the foreign market.

To test this prediction we use the information about per capita GDP ($GDPPC$) and population (POP). In our model, α_i, the intensity of demand in the domestic market, is represented by the ratio a_i/b_i where a_i is interpreted as the inverse of the marginal utility of income and b_i as the inverse of the population size. Assuming the utility of income is logarithmic, α_i then corresponds to the total GDP (see Appendix 8.1). We thus define the empirical equivalent of α_i as $ALPHA = GDPPC * POP$.

The results of the regressions are presented in Table 1. Exploiting the panel dimension of our database, all the regressions include country fixed effects and time effects. Standard errors are robust and clustered by country. Continuous variables are in logs. To avoid possible endogeneity problems, the variables describing the market size are lagged by one period (i.e., 5 years).[18] In column (a) we regress IPR against the size of the internal market $ALPHA = GDPPC * POP$ and its square. We expect the coefficient of $ALPHA$ to be negative and the coefficient of $ALPHA^2$ to be positive, which is confirmed by the estimation. This estimation considers an unbalanced panel of 118 countries. We obtain very similar and significant coefficients if we restrict the analysis to a balanced panel of 79 countries, covering the period 1965–2005.

In column (b) we add a measure of the foreign market size, which is a proxy for α_j. Following Head and Mayer (2004) and Redding and Venables (2004), we construct a measure of the foreign market potential, denoted $F-ALPHA$, using a methodology developed in the new economic geography

[18]Strong IPR protection could possibly stimulate new investment and/or FDI and in turn affect GDP. However, this channel would take some time. We reduce the risk of endogeneity by lagging the variables. Our specification is based on the implications of our theoretical model and on the existing literature on IPR (e.g., Ginarte and Park, 1997; Maskus, 2000; Chen and Puttitanun, 2005).

literature, based on the estimation of bilateral trade equations. We define

$$F - ALPHA_i = \sum_{j \neq i} GDP_j \hat{\tau}_{ij}, \quad (12)$$

where $\hat{\tau}_{ij}$ includes bilateral distances, contiguity, common language, regional trade agreements, WTO affiliation and a national border dummy (for more details on the construction of $F - ALPHA$, see appendix 10.1). Due to data limitations, in the regression and in what follows, we focus on the period 1985–2005. We expect the coefficient of $F - ALPHA$ and $F - ALPHA^2$ to have opposite sign with respect to the own-market variables, $ALPHA$ and $ALPHA^2$, which is confirmed by the estimation. The coefficients of $ALPHA$ and its square are no longer significant. However, adding relevant controls allow us to recover their statistical significance (see column (c)). These results are robust if we restrict the empirical analysis to a subsample of 101 countries whose observations are available for the entire period 1985–2005 (not shown to save space).

Table 1: IPR Equation

	(a)	(b)	(c)
ALPHA	–2.24***	–1.20	–2.32*
	(0.40)	(0.88)	(1.35)
ALPHA^2	0.05***	0.03	0.05**
	(0.01)	(0.02)	(0.03)
F-ALPHA		3.32***	3.10***
		(1.21)	(1.15)
F-ALPHA^2		–0.07**	–0.07**
		(0.03)	(0.03)
freedom			0.61*
			(0.31)
gatt/wto			0.37***
			(0.14)
N. of obs	906	553	511
N. of countries	118	118	112
Within R^2	0.75	0.68	0.71

Robust Standard Errors in parentheses, clustered by country. ***, ** and * represent respectively statistical significance at the 1%, 5% and 10% levels. All regressions include country fixed effects and time effects. All variables describing the market size and the gatt/wto variable are lagged one period.

In column (c) we add an economic freedom index, $freedom$, and a dummy indicating the year of entry into the GATT, or, later, the WTO, *gatt/wto*, as additional controls. The dummy variable *gatt/wto* is lagged one period (i.e., 5 years) as it takes time to enforce the new norms. It is intuitive that these two variables, $freedom$ and *gatt/wto*, should positively influence the level of enforcement of IPR. For instance, entering into the GATT agreements or joining the WTO imposes higher IPR standards upon joining countries. It is thus unsurprising that the coefficients of these controls are positive and significant. More importantly for our analysis, the signs of $ALPHA$, $F - ALPHA$ and their squares, do not change, and the coefficients are significant. Put together, these results imply a U-shape relationship between IPR enforcement and the relative size of a country interior market, $GAMMA = (ALPHA)/(F - ALPHA)$. The novelty of our paper with respect to previous studies by Maskus (2000), Braga, Fink, and Sepulveda (2000) and Chen and Puttitanun (2005) is to consider, in addition to the per capita income, the size of the population (and thus total GDP), as well as the country's export opportunities. Our analysis hence shows that the measure of the foreign market potential $F - ALPHA$ is crucial for explaining IPR enforcement at the domestic level. The paper empirically illuminates the relationship between IPR enforcement and trade policies.

The second set of testable implications comes from Proposition 4. The theoretical analysis shows that stricter enforcement of IPR is not necessarily conducive of more innovation at the country level, and in fact, by virtue of Proposition 1, not even at the global level. From an empirical point of view, trying to assess the impact of IPR on innovation poses a clear problem of endogeneity. According to the theory, the innovation equation should be estimated simultaneously with the equation describing the choice of IPR. However, many of the variables used to explain IPR and presented in Table 1, columns (a)–(c), are likely to be explanatory variables of innovation as well, and do not represent valid instruments for IPR in the innovation equation. We thus instrument IPR using an additional set of instruments which satisfies the exclusion restriction from the innovation equations (all tested using the Hansen J-statistics).

The choice of the instruments is discussed in detail in appendix 10.2. The first instrument is a measure of technological adoption and diffusion, namely, the number of tractors in neighboring countries (in log). Among similar indices, tractor is an appealing choice because the good data availability allows us to introduce the instrument lagged by 3 periods (15 years) to reduce endogeneity concerns. It is also in order to limit endogeneity problems that we only use information on neighbors and do not include the country itself. Tractors provide for important variation not only in the spatial dimension but also in the temporal one. It has, for instance, been shown that in the United States tractor diffusion took several decades (Manuelli and Seshadri, 2003). Finally tractor is generally used with other inputs such as certified seeds and fertilizers. This may have stimulated the enforcement of IPR in countries that wanted to take advantage of the potential increase in agricultural productivity implied by mechanization.

The second instrument is the lagged number of students from the neighboring countries studying abroad (again in order to avoid endogeneity). We expect migrant students to have an indirect effect on innovation through IPR. There are indeed several studies showing that students who spent time abroad can influence the development of institutions in their home country.[19] For example, if these students help the neighboring country to import technology, this will have an impact on the technological gap between the home country and its neighbor (either positive, if there are imitation and spillover, or negative through competition effects). Similarly, if returning students induce the adoption of institutions such as IPR in the neighboring countries, this will also affect the enforcement of IPR in the home country. Several versions of this instrument are available in the dataset proposed by Spilimbergo (2009). We have tested different specifications (deflated by the population size of the origin country) in order to retain the best instru-

[19] For instance, Spilimbergo (2009) shows that individuals educated in foreign democratic countries can promote democracy in their home country. Naghavi and Strozzi (2011) have shown that the knowledge acquired by emigrants abroad can flow back into the innovation sector at home. This is also in line with findings by Santos and Postel-Vinay (2003) and Dustmann, Fadlon, and Weiss (2011), who put the accent on the positive effects of return migration on technological transfers.

ment both in terms of exogeneity and relevance. In the equation explaining inside-the-frontier innovation (discoveries), the retained instrument is the (log of) total students from neighboring countries studying abroad aggregated into a single indicator, $Students$, by weighting them with a dummy for country contiguity and a lag of 15 years. In the equation explaining on-the-frontier innovations, the retained instrument is the (log of) students going to democratic countries, as defined by Freedom House, with bilateral distance as weights and a lag of 20 years, $Students(FH)$.[20] The coefficients of the instruments in the first-stage equations explaining IPR (including the excluded instruments) are reported in the bottom parts of Tables 2 and 3.

Proposition 4 has two sets of implications. The first set contains predictions on the level of innovation incorporated in the production of the firm in the developing country. The proposition states that this level is higher when the developing country does not enforce IPR: $\phi^P \geq \phi_2^F$. In order to assess the relevance of this result we rely on inside-the-frontier innovation, as measured by discoveries (i.e., the goods that are new in the export basket of a country, although already in production abroad; see Klinger and Lederman, 2009) on a subsample of countries which excludes the richest ones.[21]

The results are presented in Table 2. Fixed effects and time dummies are included in all specifications. In addition to the variables used as controls in the previous regression, we add the stock of human capital, *hcap*, and its square, as it can have an influence on discoveries. The variable *hcap* is the level of human capital computed with the Hall & Jones method using the new series proposed in Barro and Lee (2010). This variable does not appear to be significant and is clearly collinear with $ALPHA$, the GDP

[20] Alternative specifications give very similar results when estimating the second- stage equation, but they are more exposed to weak-instrument problems. Related tests are available upon request.

[21] For each year in our sample, we classify a country as developed if it belongs to the highest quintile in term of GDP per capita, and as developing otherwise. We discard oil-exporting countries with very high GDP per capita levels (higher than 40,000 USD with year 2000 value). All these countries, with the exception of Norway, are highly dependent on this commodity (measured as a share of exports) and exhibit low diversification of their economies. Norway is included as a developed country in the regressions, but is not considered in the distribution to set the threshold in year 2005 because its GDP per capita exceeds 40,000 USD.

Table 2: Discoveries Equation

SAMPLING:	Panel OLS	Panel IV	Neg. Binomial
	(a)	(b)	(c)
ipr	–0.16	–0.50*	–0.13*
	(0.12)	(0.27)	(0.07)
ALPHA	7.35*	5.47	9.82***
	(4.30)	(4.43)	(1.67)
ALPHA^2	–0.15*	–0.11	–0.21***
	(0.09)	(0.09)	(0.03)
F-ALPHA	–1.36	–1.19	3.07
	(3.93)	(3.88)	(2.16)
F-ALPHA^2	0.02	0.02	–0.08
	(0.10)	(0.10)	(0.06)
freedom	0.74*	0.86**	0.91***
	(0.39)	(0.42)	(0.28)
gatt/wto	0.04	0.19	0.03
	(0.15)	(0.17)	(0.11)
hcap	0.89	0.74	–1.19
	(2.32)	(2.20)	(0.95)
hcap^2	–0.06	–0.07	0.06
	(0.13)	(0.12)	(0.04)
IPR Endogenous	No	Yes	No
No. of obs	265	265	323
N. countries	56	56	70
Within R^2	0.74	–	–
Hansen (p-val.)	–	0.11	–
First-stage regs.:			
Instruments:			
Students		–0.15*	
		(0.09)	
N. of tractors		236.13***	
		(52.53)	
F (all instr.)	–	10.6	–
Partial R^2	–	.16	–

Robust Standard Errors in parentheses, clustered by country. ***, ** and * represent respectively statistical significance at the 1%, 5% and 10% levels. All regressions include country fixed effects and time effects. All variables describing the market size and the gatt/wto variable are lagged one period. First-stage regressions include all controls shown in column (d) of Table 1. Instruments are lagged three periods.

measuring the size of the internal market. However, as we will see later, the variable has an autonomous role in explaining "on-the-frontier" innovation of firms from developing countries.

For the sake of comparison we show in column (a) the result of the OLS regressions when we do not correct for the endogeneity of IPR. In column (b) IPR is instrumented by the flows of students in neighboring countries going to study abroad, and by the spatial distribution of the number of tractors. Finally, as a robustness check, column (c) presents a negative binomial estimation. This specification does not allow us to use the same instrumentation strategy, but it allows us to treat discoveries as count data.[22] In this regression, as in the instrumented cases, the coefficient of IPR is significantly negative (however, the size of the coefficient of this regression cannot be compared with the ones in the other columns because of the negative binomial functional forms). As expected from the theory, increasing IPR protection decreases within-the-frontier innovation. The size of the internal market also matters. The relationship between discoveries and α is an inverted U-shape, which is consistent with the paper result that large developing countries will be more prone to copy foreign technology than small ones. We interpret the negative coefficient of IPR as evidence that stricter IPR protection, by blocking imitation and reverse engineering, reduces the quality of domestic goods in developing countries that enforce them.

The second set of implications focuses on the level of investment in R&D and innovation developed autonomously by the firms in the developing country (i.e., on-the-frontier innovation). The paper predicts that, when IPR are enforced more strictly, the innovation of the local firm decreases in the developing country, while the innovation made by the firms of the advanced economy increases. More protection slows down on-the-frontier innovation because it makes it harder for the developing country to close the initial gap in quality levels (see Appendix 8.5). This result is supported empirically by the regressions in table 2 on discoveries. Stricter

[22]The negative binomial regression has be preferred to a Poisson estimation because the data display very strong over-dispersion.

Table 3: Patent Equation

Patent type	Resident	Non-Resid	All	Resident	Non-Resid	All
	(a)	(b)	(c)	(d)	(e)	(f)
ipr	–0.46***	0.17	0.04	–1.32***	0.38*	0.14
	(0.10)	(0.13)	(0.12)	(0.26)	(0.20)	(0.21)
ALPHA	–7.06	3.68	3.25	–17.03***	5.37	4.47
	(4.45)	(5.08)	(6.22)	(6.07)	(5.30)	(6.22)
ALPHA^2	0.18**	–0.06	–0.04	0.38***	–0.09	–0.06
	(0.09)	(0.10)	(0.12)	(0.12)	(0.11)	(0.12)
F-ALPHA	–0.85	5.57	2.87	0.44	5.66*	2.72
	(2.96)	(3.44)	(3.48)	(3.58)	(3.37)	(3.25)
F-ALPHA^2	0.02	–0.14	–0.07	–0.00	–0.14*	–0.06
	(0.07)	(0.09)	(0.09)	(0.09)	(0.08)	(0.08)
freedom	0.59**	0.37	0.63*	0.27	0.38	0.67**
	(0.28)	(0.38)	(0.37)	(0.53)	(0.33)	(0.30)
gatt/wto	–0.18	0.17	0.08	0.05	0.10	0.05
	(0.15)	(0.19)	0.14)	(0.17)	(0.18)	(0.14)
hcap	4.46*	–0.78	0.47	6.15**	–0.88	0.27
	(2.28)	(1.57)	(1.77)	(2.92)	(1.54)	(1.68)
hcap^2	–0.13	0.07	0.04	–0.26**	0.08	0.06
	(0.11)	(0.09)	(0.08)	(0.13)	(0.10)	(0.09)
IPR Endogenous	No	No	No	Yes	Yes	Yes
No. of obs	225	244	225	225	244	225
N. countries	54	59	54	54	59	54
Within R^2	0.55	0.30	0.50	–	–	–
Hansen (p-val.)	–	–	–	0.41	0.52	0.48
First-stage regs.:						
Instruments:						
N. of tractors				258.59***	243.59***	258.59***
				(52.26)	(48.29)	(52.26)
Students(FH)				–2.92*	–3.58**	–2.92*
				(1.61)	(1.56)	(1.61)
F (all instr.)	–	–	–	15.03	16.66	15.03
Partial R^2	–	–	–	.17	.18	.17

Robust Standard Errors in parentheses, clustered by country. ***, ** and * represent respectively statistical significance at the 1%, 5% and 10% levels. All regressions include country fixed effects and time effects. All variables describing the market size and the gatt/wto variable are lagged one period. First-stage regressions include all controls shown in column (d) of Table 1. Instruments are lagged several periods (see the text for details).

enforcement of IPR reduces technological transfer and reverse engineering (i.e., on within-the-frontier innovation). This in turn affects the capacity to genuinely innovate. To test this second set of predictions, we use data on patents as a proxy for on-the-frontier innovation. We focus on the subsample of less developed countries (i.e., excluding the highest income quintile) and we measure on-the-frontier innovation as the number of patent applications made by resident firms. Symmetrically, innovations made by firms from the developed countries are proxied by the number of patent applications made by non-resident firms.[23] We first show (i.e., in columns (a), (b) (c)) the result of the regressions when we do not correct for the endogeneity of IPR, and next, in columns (d), (e), (f), IPR is instrumented using the flows of students in neighboring countries going to study in democratic countries (as defined by Freedom House), and the spatial distribution of the number of tractors. The first-stage regressions confirm that the instruments are adequate. The regressions presented in Table 3 pass the exogeneity and relevance tests. As a last robustness check, we run all IV regressions using alternative estimation methods that are robust to weak instruments. In particular, we use the Limited Information Maximum Likelihood (LIML) and Fuller's modified LIML (See Murray, 2011 for details). We find virtually the same coefficients for the IPR variable. All these robustness checks are available upon request.

The results, shown in Table 3, confirm that failing to correct for endogeneity bias leads to an underestimation of the impact of IPR on innovation activities. Increasing IPR enforcement decreases on-the-frontier innovation of resident firms in developing countries (resident patents) but increases innovation of nonresident firms (which are mostly firms based in developed countries). In the non-resident equation the sign of $ALPHA$ and their squares is hence inverted (although not statistically significant) because the incentive of foreign firms to invest in patents depends positively on the size of the internal market of the developing countries. The two effects cancel out when the two sets of patents are merged (see the "All"

[23] The vast majority of patents of non-resident firms in the world originate from firms located in high-income economies. For more on this see "World Intellectual Property Indicators" 2011 WIPO Economics & Statistics Series at www.wipo.int.

regression). This result contradicts the idea that stronger enforcement of IPR in developing countries will lead to more patents at the global level. Our results show that the total number of patents is not affected: there is simply a substitution between domestic and foreign patents when IPR is more strongly enforced. This regression illuminates the conflict which sets advanced and developing countries in opposition regarding TRIPS and more generally in matters of strong IPR enforcement.

7 Conclusion

By stressing the role of technical development, market size and export opportunity, the paper provides a comprehensive theoretical explanation of the different impact of IPR protection in developing and developed countries. The paper contributes to the understanding of the forces that can encourage/discourage innovation at the global level by focusing on two issues: first the incentives that developing countries might have to enforce IPR, and second the impact of their choices on global innovation. The empirical analysis adds on the theory by identifying which factors are the most relevant in practice.

The analysis illuminates that patent enforcement is a U-shape function of the relative size of the domestic market with respect to export opportunities. It also shows that the IPR regime, which maximizes global innovation and R&D investment, depends both on the maturity of the R&D system and on the size of the developing country's internal market. When developing countries are pure free-rider the global level of investment in R&D is higher under an uniform IPR regime. However, with the emergence of new players in the R&D world system, such as China and India, the results are reversed. An asymmetric enforcement of IPR, weak in the South and strong in the North, implies that the investment levels in R&D of Northern and Southern firms are a strategic complement. They reinforce each other so that total investment is larger with partial enforcement of IPR than with universal enforcement.

Taking into account the difference between on-the-frontier and inside-the-frontier innovation on the manufacturing sectors of a wide panel of countries, our empirical results offer support to the main insight of the theoretical analysis. More protection slows down on-the frontier-innovation because it makes harder for the developing countries to close their initial technological gap. Our results shows that uniform IPR protection, as opposed to partial protection, is detrimental to both imitation-driven innovation and on-the-frontier innovation (as measured by patent activity) in the developing countries, without a clear benefit on global R&D activities. This result contradicts the idea that stronger enforcement of IPR in developing countries will lead to more patents at the global level.

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8 Appendix: For Online Publication

8.1 Demand

Our demand is a quality augmented version of the linear demand model for differentiated goods proposed by Singh and Vives (1984), which is based on a standard quadratic utility function. Quality augmented versions of the Singh and Vives (1984) model were initially introduced by Sutton (1991, 1997). Symeonidis (2003) has subsequently modeled in a similar framework quality-enhancing innovation in a model with horizontally differentiated goods and R&D spillovers. His model includes horizontal differentiation but allows only to characterize symmetric investment equilibria (i.e. firms have identical technologies and equal equilibrium levels of innovation). Our model considers heterogeneous technologies leading to different equilibrium level of innovations, but does not introduce horizontal differentiation. It concentrates on vertical differentiation (quality improvements).

In equation 1, a_j is interpreted as the per capita income and b_j as the *inverse* of the population size of country j. To see this point let the indirect utility of a representative consumer consuming two goods of quality v_1 and v_2 be $V(w, x_1, x_2) = u(w) + v_1 x_1 + v_2 x_2 - \frac{(x_1+x_2)^2}{2}$, where x_i is the quantity of good $i = 1, 2$ and u is a concave function of consumer net income $w = R - p_1 x_1 - p_2 x_2$. Optimizing V with respect to x_i yields: $\frac{\partial V}{\partial x_i} = -u'(w)p_i + v_i - (x_1 + x_2)$ $(i = 1, 2)$. If $\frac{1}{u'(w)} v_i - p_i > \frac{1}{u'(w)} v_j - p_j$ then $x_j = 0$ and $x_i = v_i - u'(w)p_i$. If $\frac{1}{u'(w)} v_i - p_i = \frac{1}{u'(w)} v_j - p_j$ the representative consumer demand is $x_1 + x_2 = v_i - u'(w)p_i$. If N is the size of the population the total demand is $q_1 + q_2 = Nv_i - Nu'(w)p_i$. Letting $b \equiv \frac{1}{N}$ and $a \cong u'(w)$, the aggregated inverse demand for good $i = 1, 2$ is $p_i = a(v_i - b(q_1 + q_2))$. With two countries, the price of good i in country j becomes p_{ij}, and the total quantity in country j, $q_{1j} + q_{2j}$, yielding (1). If the price of the two commodities is relatively small compared to the income, a can thus be interpreted as the inverse of marginal utility of income, which is in general an increasing function of per capita income (see Tirole, 1988). In our model $u(w) = log(w)$, and thus the inverse of the marginal utility of income corresponds precisely to per capita income.

Recent empirical studies have assessed the pertinence of the widespread use of the logarithmic form for the utility of income, providing new estimates. They start with the more general specification:

$$u(R) = \begin{cases} \frac{(R^(1-\rho)-1}{1-\rho}, & \text{if } \rho \neq 1; \\ log(R), & \text{if } \rho = 1. \end{cases} \tag{13}$$

For instance, Layard et al. (2008) estimate $\rho \simeq 1.2$. In this case, the empirical equivalent of our α_2 can be recalculated as ALPHA=GDPPC$^{1.2}$*POP. We tried this specification in our estimations: it does not qualitatively change the empirical results nor significantly affect the magnitude of the effects (estimations available on request). For simplicity, we thus stick to $u(y) = log(y)$.

8.2 Proof of Proposition 1

To show the robustness of our main result to the presence of transportation costs, we assume that exporting to a foreign country implies a unit transportation cost equal to $t \geq 0$. We derive the computations under this general case. The results of the base model are simply obtained by fixing $t = 0$.

In the open economy, the total profit of firm i is written as:

$$\Pi_i^D = p_{i1}q_{i1} + p_{i2}q_{i2} - tq_{ij} - k_i\frac{\phi_i^2}{2} \tag{14}$$

At the second stage, the Cournot quantity produced by firm i in country j becomes:

$$q_{ij}^D = \frac{2v_i^I - v_{-i}^I}{3b_j} + \frac{2t}{3a_ib_j}\ , \qquad i, -i, j \in \{1, 2\}, i \neq -i \tag{15}$$

where the index $-i$ represents the competitor and the value of v_i^I depends on the IPR regime, i.e., $v_i^I \in \{v_i^F, v_i^N, v_i^P\}$.

- *The socially optimal level of investment*:

  Optimizing (7) with the profit function being replaced by (14) and the quantity formula by (15), the socially optimal level of innovation in country i becomes:

$$\phi_i^* = \frac{\alpha - t\frac{b_1+b_2}{2b_1b_2}}{\frac{9}{8}\frac{k_1k_2}{k_1+k_2} - \alpha} \frac{k_j}{k_1+k_2} \tag{16}$$

Recall that $\Delta = \frac{k_2}{k_1}$ and that under assumption 1 $k_1 = 2\alpha = 2(\alpha_1 + \alpha_2)$. Then the optimal level of innovation in the common market, $\phi^* = \phi_1^* + \phi_2^*$, is:

$$\phi^* = \frac{4(\Delta+1)}{5\Delta-4} - \frac{t}{\alpha b_1 b_2} \frac{2(\Delta+1)}{5\Delta-4} \tag{17}$$

For $t = 0$, this corresponds to equation (8). For $t > 0$, the symmetry between the two countries is broken: the higher the population size $1/b_i$ ($i = 1, 2$), the higher the investment. Moreover, a decrease in transportation costs always increases investment, and this effect is larger when the population of the two countries increases.

- *Full IPR protection (F regime)*:

  Substituting the quantities (15) in the profit function, firm i maximizes (14) with respect to ϕ_i, for a given level of ϕ_j, $i \neq j$. Profit maximization gives the reaction function:

$$\phi_i(\phi_j) = \frac{\alpha(1-\phi_j) - \frac{2b_i - b_j}{b_i b_j} t}{2.25k_i - 2\alpha} \tag{18}$$

  The slope of the reaction function is negative: $\frac{\partial \phi_i(\phi_j)}{\partial \phi_j} < 0$. Quality levels (and thus investment levels) are *strategic substitutes*. When i innovates, commodity i becomes more valuable to the consumer. Other things being equal, this decreases the demand for good j and the incentive of firm j to innovate. This is a pure competition effect that passes through substitution. When the quality of a good is increased, this not only increases the demand for this good but decreases the demand for the competitor's good which becomes of lower relative quality. Moreover, the slope of the reaction function does not depend on the transportation cost t, which only affects the intercept of the function. When $t = 0$, investment does not depend on local market characteristics but only on total demand and on the cost of R&D investment k_i. Then, if $k_1 = k_2$, firms invest the same amount in R&D and produce the same quality. When $k_1 = k_2$ and $t > 0$, an increase in the relative size of demand i shifts the reaction function of firm i upwards. As a consequence, firm i invests more than firm j if and only if $1/b_i > 1/b_j$ (i.e., the country i has a larger population). Solving the system of first-order conditions, we obtain:

$$\phi_i^F = \frac{1}{2} \frac{\alpha(1 - \frac{\alpha}{3k_j})\frac{k_j}{k_1+k_2} - \frac{t}{k_1+k_2}(k_j(\frac{2}{b_j} - \frac{1}{b_i}) - \frac{4\alpha}{3b_j})}{\frac{9}{8}\frac{k_1 k_2}{k_1+k_2} - \alpha(1 - \frac{\alpha}{3\frac{k_1+k_2}{2}})} \tag{19}$$

The level of quality chosen by firm i depends negatively on k_i and positively on k_j, the parameter describing the competitor's cost of innovation. Moreover ϕ_i^F decreases with t if and only if $\frac{b_j}{b_i} \leq 2 - \frac{4}{3}\frac{\alpha}{k_j}$. This inequality is easier to satisfy when k_j increases. Let $\Delta = \frac{k_2}{k_1}$. Under assumption 1, the two equilibrium investment levels can be written as:

$$\phi_1^F = \frac{6\Delta - 4}{15\Delta - 8} - \frac{t}{\alpha}\frac{6(\frac{2}{b_2} - \frac{1}{b_1})\Delta - \frac{4}{b_2}}{15\Delta - 8} \tag{20}$$

$$\phi_2^F = \frac{5}{15\Delta - 8} - \frac{t}{\alpha}\frac{(\frac{4}{3b_1} - \frac{1}{b_2})}{15\Delta - 8} \tag{21}$$

Setting $t = 0$ we find that the highest quality available to consumers is $\phi^F = \phi_1^F$, which yields equation (9).

On the other hand, when $t > 0$, the relative size of the internal market matters. Firms in larger markets invest more than competitors operating in smaller ones. Moreover, a decrease of the transportation cost increases the level of investment of country i if and only if country j is relatively large in terms of population.[24] The prospect of competing in a large foreign market increases the incentive to invest. On the contrary, when the foreign market is relatively small, a decrease in transportation costs tends to increase the negative impact

[24]Interestingly, the same effect does not occur when per capita revenue increases. Starting from a symmetric situation ($a_i = a_j$), if the revenue of a country increases, both firms invest more, but the investment levels remain symmetrical. This can explain why larger countries tend to invest more in R&D, independently of income levels. For instance, countries like China and India invest more than smaller countries with similar per capita income characteristics.

of competition on domestic profits, and thus to reduce the level of investment.

- *No IPR protection (N regime)*:

  When IPR are not protected, the quality of good i after investment is given by $\phi^N = \phi_1^N + \phi_2^N$. At the second stage, quantities are given by the Cournot levels in (4). At the first stage, profit maximization gives the reaction functions:

$$\phi_i(\phi_j) = \frac{\alpha(1+\phi_j) - \frac{2b_i - b_j}{b_i b_j} t}{4.5k_i - \alpha} \tag{22}$$

  In this case the slope of the reaction function is positive:

$$\frac{\partial \phi_i(\phi_j)}{\partial \phi_j} > 0$$

  Quality levels (and thus investment) are *strategic complements*. This result is counter-intuitive because free-riding behaviors are associated with under-investment problems. Nevertheless, focusing on the reaction function, the more the competitor invests the more the national firm wants to invest in its own R&D activity. The level of investments in innovation become strategic complements when technological transfers occur. Because of imitation, when firm i innovates this has a positive impact on the demand for good j. The size of the market for the two goods increases. Then, the incentive of j to innovate is also enhanced. If the firm can exploit the innovation developed by its competitor without losing the benefit of its own innovation, to win market shares it tends to invest more when its competitor invests more.

  The role played by the transportation cost is equivalent to that in the F case. When the transportation cost is positive, countries with a larger population tend to invest more than smaller ones. We have:

$$\phi_i^N = \frac{\alpha \frac{k_j}{k_1+k_2} - \frac{t}{k_1+k_2}\left(k_j\left(\frac{2}{b_j} - \frac{1}{b_i}\right) - \frac{2}{3}\alpha\left(\frac{1}{b_j} - \frac{1}{b_i}\right)\right)}{4.5\frac{k_1 k_2}{k_1+k_2} - \alpha} \tag{23}$$

As before, investment in country i increases with k_j and decreases with k_i. Moreover, ϕ_i^N decreases with t if and only if $\frac{b_j}{b_i} \leq \frac{2(3k_j-\alpha)}{3k_j-2\alpha}$. This inequality is easier to satisfy when k_j decreases. Moreover, a decrease of the transportation cost increases the level of investment of country i if and only if country j's population is relatively large.

Under assumption 1, the total quality under N can be written as:

$$\phi^N = \phi_1^N + \phi_2^N = \frac{\Delta + 1}{8\Delta - 1} - \frac{t}{\alpha} \frac{((\frac{1}{b_2} - \frac{2}{b_1}) + (\frac{1}{b_1} - \frac{2}{b_2})\Delta)}{8\Delta - 1} \tag{24}$$

For $t = 0$, this corresponds to equation (10). For $t > 0$, a decrease of the transportation cost increases the total level of investment if and only if the two countries have sufficiently different sizes.

Contrary to case F, a decrease of transportation cost is not always conducive to more investment in R&D. The net effect depends on the relative size of the two markets and on the technological gap between the two countries. The larger is Δ, the competitive advantage of firm 1 in terms of R&D technology, the less likely it is that a reduction in transportation costs increases the global investment in R&D. Indeed, a reduction of transportation costs implies an increase in the intensity of competition on domestic markets. This business-stealing effect discourages firm 1 from investing when free riding (i.e., Δ) is large. This effect is also relevant when the advanced economy enforces IPR, but enforcement is imperfect (the case of imperfect enforcement is illustrated in Appendix 9.3).

- *IPR protection only in one country (P regime)*:

When only one country protects IPR, the quality of good i after investment is given by $\phi^P = \phi_1^P + \phi_2^P$. If firm 2 chooses imitation, it will sell only in country 2. Then, firm 1 is a monopoly in country 1 and competes with 2 à la Cournot in country 2. At the second stage, quantities are given by the Cournot levels in (15). At the first stage, profit maximization gives the reaction functions:

$$\phi_1(\phi_2) \quad = \quad \frac{(1 + \phi_j)(2.25\alpha_1 + \alpha_2) - \frac{2t}{b_2}}{4.5k_1 - (2.25\alpha_1 + \alpha_2)} \tag{25}$$

$$\phi_2(\phi_1) = \frac{(1+\phi_1)\alpha_2 + \frac{t}{b_2}}{4.5k_2 - \alpha_2} \tag{26}$$

In the case of partial enforcement of IPR, investments are *strategic complements*. That is, the slope of reaction function is positive for both firms: $\frac{\partial\phi_i(\phi_j)}{\partial\phi_j} > 0 \;\; i,j = 1,2 \; i \neq j$. The slope is larger for firm 1 because it sells its production in both countries. By contrast, firm 2 sells only in country 2. Nevertheless, the slope of its reaction function is positive because technological transfers from firm 1 expand domestic demand. Confronted with a larger demand, the firm 2 optimally increases its investment level. Since it has no access to the foreign market, its incentives to invest are lower than that of firm 1.

Solving for the equilibrium we have:

$$\phi_1^P = \frac{(2.25\alpha_1+\alpha_2)k_2 - \frac{t}{b_2}(2k_2 - \frac{1}{2}\alpha_1 - \frac{2}{3}\alpha_2)}{4.5k_1k_2 - (2.25\alpha_1+\alpha_2)k_2 - \alpha_2 k_1} \tag{27}$$

$$\phi_2^P = \frac{\alpha_2 k_1 + \frac{t}{b_2}(k_1 - \frac{1}{2}\alpha_1 - \frac{2}{3}\alpha_2)}{4.5k_1k_2 - (2.25\alpha_1+\alpha_2)k_2 - \alpha_2 k_1} \tag{28}$$

Let $\gamma = \frac{\alpha_2}{\alpha_1}$ and $\Delta = \frac{k_2}{k_1}$. Under assumption 1, the total level of investment under regime P, $\phi^P = \phi_1^P + \phi_2^P$, is:

$$\phi^P = \frac{9\Delta + 4\gamma(\Delta+1)}{27\Delta + 4\gamma(8\Delta-1)} - \frac{t}{b_2\alpha_1}\frac{8(\Delta-1)}{27\Delta+4\gamma(8\Delta-1)} \tag{29}$$

For $t = 0$, this corresponds to equation (11). For $t > 0$, a decrease in the transportation cost increases the level of investment, and this effect is more important when the size of population in country 2 increases (i.e., b_2 is small). In fact, the only possible trade in this case goes from country 1 to country 2.

- *Comparison of the IPR regimes*

Using (17), (24), and (29) it is easy to check that $\phi^* > \phi^P > \phi^N$. A more challenging issue is to compare ϕ^F with ϕ^P.

Proof of Proposition 1: Let $t = 0$. In this case, one can check that the difference $\phi^F - \phi^P$ is increasing in Δ:

$$\frac{\partial(\phi^F - \phi^P)}{\partial\Delta} = 12\left(\frac{12\gamma(\gamma+1)}{(27\Delta+4\gamma(8\Delta-1))^2} + \frac{1}{(15\Delta-8)^2}\right) \geq 0 \tag{30}$$

Moreover, at the lowest admissible value (i.e., $\Delta \to 1$) the difference is negative, while it is positive for the very high value (i.e., $\Delta \to \infty$).

$$(\phi^F - \phi^P)|_{\Delta \to 1} = -\frac{9}{7(28\gamma + 27)} \leq 0$$
$$(\phi^F - \phi^P)|_{\Delta \to \infty} = \frac{44\gamma + 9}{160\gamma + 135} \geq 0$$

We deduce that there exists a positive threshold

$$\Delta(\gamma) = \frac{2\left(15\gamma + \sqrt{\gamma(49\gamma + 54) + 9} + 3\right)}{44\gamma + 9} \in [1, 4/3]$$

such that $\phi^F - \phi^P \geq 0$ if and only if $\Delta \geq \Delta(\gamma)$. This threshold is decreasing in γ for all positive values of γ and varies between 1 and 4/3. We deduce the result in Proposition 1.

Now consider $t > 0$. In this case, when t is large and b_2 relatively small, ϕ_2^F might be greater than ϕ_1^F (see equation (19)). This happens when $t \geq \frac{3b_2\alpha(\Delta-1)}{1-4\frac{b_2}{b_1}+3(2-\frac{b_2}{b_1})\Delta}$ (or equivalently $\frac{b_2}{b_1} \leq \frac{t(6\Delta-1)}{3b_1\alpha(\Delta-1)+t(3\Delta+4)}$). Intuitively, if the population of country 2 and the transportation costs are large while Δ is small, the incentives to innovate might be larger in country 2 than in country 1 (because firm 1 supports additional costs to sell to consumers in country 2 which decrease its incentives to innovate). Then, we label $\phi^F = \max\{\phi_1^F, \phi_1^F\}$. Taking this point into account and using (19) and (29), we can check that, if t is not too large, Proposition 1 still holds. To see this point, consider $t < \left|\frac{9\alpha b_2}{95+98\gamma-4\frac{b_2}{b_1}(27+28\gamma)}\right|$. In this case, the following proposition holds, analogous to Proposition 1 :

Proposition 1*bis* *There exists a threshold value* $\Delta(\gamma, b_1, b_2, t)$ *such that:*

- If $\Delta \leq \Delta(\gamma, b_1, b_2, t)$ then $\phi^N \leq \phi^F \leq \phi^P \leq \phi^*$
- If $\Delta > \Delta(\gamma, b_2, \frac{b_1}{b_2}, t)$ then $\phi^N \leq \phi^P < \phi^F \leq \phi^*$.

Moreover, when $\frac{b_2}{b1} \leq \frac{2(\gamma(6\Delta+1)(11\Delta-4)+\Delta(51\Delta+4)-8)}{3\Delta(4\gamma(8\Delta-1)+27\Delta)}$, the threshold $\Delta(\gamma, b_1, b_2, t)$ increases with t (which means that, for higher values of t, there exist more admissible values of Δ for which $\phi^P \geq \phi^F$ with respect to the base case). On the contrary, when $\frac{b_2}{b1} > \frac{2(\gamma(6\Delta+1)(11\Delta-4)+\Delta(51\Delta+4)-8)}{3\Delta(4\gamma(8\Delta-1)+27\Delta)}$, the opposite holds (which means that, for higher t, there exist more admissible values of Δ for which $\phi^F \geq \phi^P$ with respect to the base case).

8.3 Proof of Proposition 2

Under full protection of IPR (F), welfare in country $i = 1, 2$ is:

$$W_i^F = \frac{1}{18}\left[3\alpha_i\Big(2(1+\phi_i^F)^2 + (\phi_i^F - \phi_j^F)^2\Big) + 2\alpha_j(1 + 2\phi_i^F - \phi_j^F)^2\right] - k_i\frac{(\phi_i^F)^2}{2} \tag{31}$$

Substituting the investment equilibrium value, (20) and (21) where $t = 0$, welfare under full protection of IPR can be written as:

$$W_2^F = \frac{\alpha(\gamma(\Delta(81\Delta-76)+18)+\Delta(9\Delta-4))}{(\gamma+1)(8-15\Delta)^2} \tag{32}$$

Under no protection of IPR (N), welfare in country $i = 1, 2$ is:

$$W_i^N = \frac{1}{9}(3\alpha_i + \alpha_j)(1 + \phi_1^N + \phi_2^N)^2 - k_i\frac{(\phi_i^N)^2}{2} \tag{33}$$

Setting $t = 0$ in (23), the investment equilibrium levels are $\phi_1^N = \frac{\Delta}{8\Delta-1}$ and $\phi_2^N = \frac{1}{8\Delta-1}$. Substituting these values in country 2's welfare function yields, after some rewriting:

$$W_2^N = \frac{\alpha\Delta(\gamma(27\Delta-1)+9\Delta-1)}{(\gamma+1)(1-8\Delta)^2} \tag{34}$$

Under partial protection (P) welfare in country 1 and 2 is asymmetric. In country 2 it is:

$$W_2^P = \frac{1}{3}\alpha_2(1+\phi_1^P+\phi_2^P)^2 - k_2\frac{(\phi_2^P)^2}{2} \tag{35}$$

Setting $t = 0$ in (27) and (28), the investment equilibrium levels are $\phi_1^P = \frac{(9+4\gamma)\Delta}{27\Delta+4\gamma(8\Delta-1)}$ and $\phi_2^P = \frac{4\gamma}{27\Delta+4\gamma(8\Delta-1)}$. Substituting these values in country 2's welfare function yields:

$$W_2^P = \frac{16\alpha\gamma\Delta(27(\gamma+1)\Delta-\gamma)}{(4\gamma(8\Delta-1)+27\Delta)^2} \tag{36}$$

Using (32) and (36), we can write the welfare different $W_2^F - W_2^P$ as:

$$\frac{W_2^F - W_2^P}{\alpha} = \frac{-16\Delta\gamma(27\Delta(1+\gamma)-\gamma)}{(\Delta(27+32\gamma)-4\gamma)^2} + \frac{\Delta(9\Delta(1+9\gamma)-76\gamma-4)+18\gamma}{(15\Delta-8)^2(1+\gamma)} \tag{37}$$

It is straightforward to check that:

$$\frac{W_2^F - W_2^P}{\alpha}|_{\Delta\to 1} = \frac{3645-3\gamma(56\gamma(14\gamma+17)-1053)}{49(\gamma+1)(28\gamma+27)^2}$$
$$\frac{W_2^F - W_2^P}{\alpha}|_{\Delta\to \infty} = \frac{729-\gamma(16\gamma(99\gamma+314)+2511)}{25(\gamma+1)(32\gamma+27)^2}$$

At the lowest admissible value $\Delta \to 1$, the difference $W_2^F - W_2^P$ is positive if and only if $\gamma \leq \overline{\gamma} = 1.14$. At the other extreme, when $\Delta \to \infty$, the difference $W_2^F - W_2^P$ is positive if and only if $\gamma \leq \underline{\gamma} = 0.2$. Moreover, one can check that

$$\frac{\partial(W_2^F - W_2^P)}{\partial\Delta} = -\alpha\left(\frac{12\Delta(13\gamma+7)-32-68\gamma}{(15\Delta-8)^3(1+\gamma)} - \frac{16\gamma^2(\Delta(189+184\gamma)-4\gamma)}{(\Delta(27+32\gamma)-4\gamma)^3}\right) \tag{38}$$

The difference $W_2^F - W_2^P$ is decreasing in Δ for sufficiently small γ. In particular, it is decreasing for $\gamma \leq \overline{\gamma}$ (sufficient condition). We deduce that

- For $\gamma < \underline{\gamma}$, $W_2^F - W_2^P$ is always positive.
- For $\underline{\gamma} \leq \gamma \leq \overline{\gamma}$, $W_2^F - W_2^P$ is positive in $\Delta \to 1$ and negative in $\Delta \to \infty$. Since $W_2^F - W_2^P$ is decreasing, there is a threshold value $\Delta_2(\gamma) > 0$ such that $W_2^F \geq W_2^P$ if and only if $\Delta \leq \Delta_2(\gamma)$.
- For $\gamma > \overline{\gamma}$, the derivative $\frac{\partial(W_2^F - W_2^P)}{\partial\Delta}$ is increasing in γ. For high values of γ, $W_2^F - W_2^P$ is first decreasing and then increasing in Δ. However, at the two extremes, $\Delta \to 1$ and $\Delta \to \infty$, $W_2^F - W_2^P$ is negative for all values of $\gamma > 0$. Then, $W_2^F - W_2^P$ is always negative.

8.4 Proof of Proposition 3

The proof is similar to the proof of Proposition 2. Under full protection of IPR (F), welfare in country $i = 1$ is defined as in (31), and under no protection (N) it is defined as in (33), while under partial protection (P) it is:

$$W_1^P = \frac{1}{72}(27\alpha_1 + 8\alpha_2)(1 + \phi_1^P + \phi_2^P)^2 - k_1\frac{(\phi_1^P)^2}{2} \tag{39}$$

Substituting the investment equilibrium value, under assumption 1, welfare under full protection of IPR (F) can be rewritten as:

$$W_1^F = \frac{\alpha\left(5\gamma(2-3\Delta)^2 + 3\Delta(39\Delta - 44) + 38\right)}{(\gamma+1)(8-15\Delta)^2} \tag{40}$$

Under partial protection (P) it is:

$$W_1^P = \frac{\alpha(2\gamma(64\gamma+279)+405)\Delta^2}{(4\gamma(8\Delta-1)+27\Delta)^2} \tag{41}$$

Finally, under no protection (N) it is:

$$W_1^N = \frac{2\alpha(4\gamma+13)\Delta^2}{(\gamma+1)(1-8\Delta)^2} \tag{42}$$

Comparing equation (40) with (41) one can check that:

$$\begin{aligned}(W_1^F - W_1^P)|_{\Delta\to 1} &= -\frac{6\alpha(\gamma(7\gamma(56\gamma+191)+1461)+513)}{49(\gamma+1)(28\gamma+27)^2}\\ (W_1^F - W_1^P)|_{\Delta\to\infty} &= \frac{\alpha(2\gamma(\gamma(960\gamma+2401)+1017)-648)}{25(\gamma+1)(32\gamma+27)^2}\end{aligned}$$

Moreover,

$$\frac{\partial(W_1^F - W_1^P)}{\partial\Delta} = \frac{4\alpha}{5(\gamma+1)}(5\gamma\Big(\frac{2(\gamma+1)(2\gamma(64\gamma+279)+405)\Delta}{(4\gamma(8\Delta-1)+27\Delta)^3} + \frac{15(3\Delta-2)}{(15\Delta-8)^3}\Big) + \frac{15(9\Delta-7)}{(15\Delta-8)^3}\Big) \tag{43}$$

We deduce that the difference $W_1^F - W_1^P$ is increasing in Δ. At the lowest admissible value $\Delta \to 1$, the difference is negative. At the other extreme $\Delta \to \infty$, $W_1^F - W_1^P$ is positive if and only if $\gamma > 0.21 = \gamma_1$. Then,

- For $\gamma \leq \gamma_1$ $W_1^F - W_1^P$ is always negative.
- For $\gamma > \gamma_1$, $W_1^F - W_1^P$ is negative when $\Delta \to 1$ and positive when $\Delta \to \infty$. Since $W_1^F - W_1^P$ is increasing, there is a threshold value $\Delta_1(\gamma)$ such that $W_1^F \geq W_1^P$ if and only if $\Delta \geq \Delta_1(\gamma)$.

8.5 Proof of Proposition 4

We assume that before investment the quality of firm 1 is $v_1 = 1$ and the quality of firm 2 is $v_2 = 1 - d$. Under regime P, this gap is closed by imitation and everything is as in the base case. Under regime F, the quality of firm 1 after innovation will be $v_1^F = 1 + \phi_1^F$ and the quality of firm 2 $v_1^F = 1 - d + \phi_2^F$. Solving for the optimal level of investment we obtain that the level of investment of firm 2 is:

$$\phi_{2d}^F = \max\left\{\frac{2-8d}{15\Delta-8}, 0\right\} \tag{44}$$

and firm 1's investment is:

$$\phi_{1d}^F = \tfrac{6(1+d)\Delta-4}{15\Delta-8} \quad if \;\; \phi_{2d}^F > 0; \tag{45}$$

$$\phi_{1d}^F = \tfrac{2}{5}(1+d) \quad otherwise. \tag{46}$$

As intuition suggests, ϕ_{1d}^F increases and ϕ_{2d}^F decreases in d. Comparing equation (44) with (28) it is straightforward to verify that, for $d \geq \hat{d} = \frac{27\Delta+2(6+\Delta)\gamma}{27\Delta+4(32\Delta-4)\gamma}$, ϕ_{d2}^F is smaller than ϕ_2^P. Similarly, comparing equation (45) with (27) (for $t = 0$) it can be verified that, for $d \geq \tilde{d} = \frac{3\Delta(12+40\gamma-\Delta(44\gamma+9))-16\gamma}{6\Delta(\Delta(32\gamma+27)-4\gamma)}$, ϕ_{d1}^F is larger than ϕ_1^P.

We note that for $\gamma \geq 0.32$, $\tilde{d}$ is negative for all $\Delta \geq 1$ and so ϕ_{d1}^F is always larger than ϕ_1^P. For smaller values of γ, $\tilde{d}$ can be positive if $\Delta \leq \frac{2(9+30\gamma+\sqrt{81+12\gamma(36+31\gamma)})}{3(9+44\gamma)} \leq \frac{4}{3}$, and it is negative otherwise. Then, $\gamma \geq 1/3$ or $\Delta \geq 4/3$ are sufficient conditions for ϕ_{d1}^F always to be larger than ϕ_1^P. Moreover, one can also show that W_1^F is increasing in d while W_2^F is decreasing in d: when the developing country has an initial disadvantage, it is more likely to prefer not to enforce IPR.

8.6 Welfare analysis

We conclude the theoretical analysis by a brief presentation of the optimal policy from a collective utilitarian point of view. A normative approach might help to look for a better compromise between the South and the North. It turns out that $W_1^F + W_2^F$, the total welfare under regime F, does not behave smoothly. For this reason, comparison with regime P is not straightforward. Figure 2 illustrates the non-monotonicity of total welfare with respect to γ for high values of Δ (i.e., for high levels of Δ, F is socially preferable than P if γ is either very small or very large). When γ is small, country 2 prefers F and country 1 prefers P but the losses of country 1 are smaller than the gains of 2 and F is preferred from a global point of view. In this case the choice of IPR enforcement by 2 is efficient. On the contrary, when γ is very large (i.e., country 2 is very large or becomes richer), country 1 prefers F and country 2 prefers P, while the losses of country 1 are larger than the gains of country 2. Then F should be preferred at the global level, but country 2 has no incentive to enforce IPR. These results hold true especially when country 2 does not do any R&D at all ($\Delta \to \infty$).

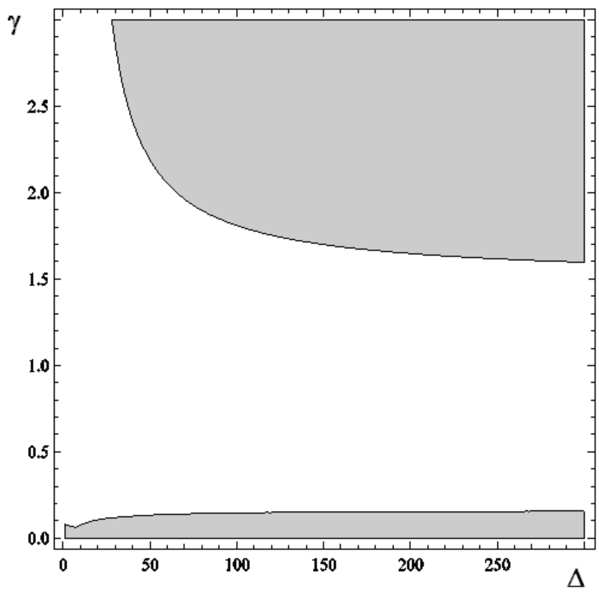


Figure 2: Total welfare difference: $(W_1^F + W_2^F) - (W_1^P + W_2^P)$. In the colored region $(W_1^F + W_2^F) - (W_1^P + W_2^P) > 0$.

By contrast when country 2 has developed an efficient R&D system (i.e., when Δ is small), welfare is higher under a partial system P than under a full system F, unless γ is very small. Since developing countries that have managed to set up competitive R&D systems are fast-emerging countries with large interior markets, such as India or China, the most relevant case is one of a relatively large γ. This result suggests that as an emerging country moves from zero to substantial investment levels in R&D, partial IPR become more attractive from a global point of view, as it is conducive of a higher level of investment at the global level and of total market and demand growth. Yet this is also the case where generally the developing country will start to enforce IPR (see Proposition 2 and figure 1).

9 Robustness checks

9.1 Relaxing Assumption 1

Under assumption 1 we have assumed that k_1 is small, i.e., close to the smallest admissible value $16/9\alpha$. This simplifying assumption makes our problem meaningful, because it ensures that innovation is non-negligible (because it is not too costly, at least for country 1) and that country 2 has an incentive to imitate foreign technology for reasonable values of the parameters. When k_1 (and thus $k_2 = \Delta k_1$) is very large these incentives for country 2 are drastically reduced. To see this point consider the limit case $k_1 \to \infty$, then $\phi_1^P = \phi_2^P = \phi_1^F = \phi_2^F \to 0$. Substituting these limit values in the welfare functions (see equations (31) and (35)) we obtain that $W_2^F - W_2^P \to \frac{1}{9}(3\alpha_2 + \alpha_1) - \frac{1}{3}\alpha_2 = \frac{1}{9}\alpha_1 > 0$. By continuity, the regions of the parameter for which this dominance result of F over P holds is negligible for large-enough values of k_1. When k_1 is very large, free-riding on country 1's innovation is not worthwhile, because there is not much to copy. Country 2 chooses the F regime to be able to export and to sell its production in country 1.

For smaller values of k_1, the qualitative results in the paper hold, while the regions of the parameters for which country 2 prefers P to F shrink when k_1 increases. To see this, let us replace assumption 1 with a more general assumption:

$$k_1 = \underline{k}\alpha \tag{47}$$

with $\underline{k} > 2$. In this case, the investment levels become:

$$\phi^*_{\underline{k}} = \frac{8(\Delta + 1)}{(9\underline{k} - 8)\Delta - 8}$$
$$\phi^F_{\underline{k}} = \frac{4(3\underline{k}\Delta - 4)}{3\underline{k}((9\underline{k} - 8)\Delta - 8) + 16}$$
$$\phi^P_{\underline{k}} = \frac{9\Delta + 4\gamma(\Delta + 1)}{\Delta(18\underline{k}(1 + \gamma) - 4\gamma - 9) - 4\gamma}$$
$$\phi^N_{\underline{k}} = \frac{2(\Delta + 1)}{(9\underline{k} - 2)\Delta - 2}$$

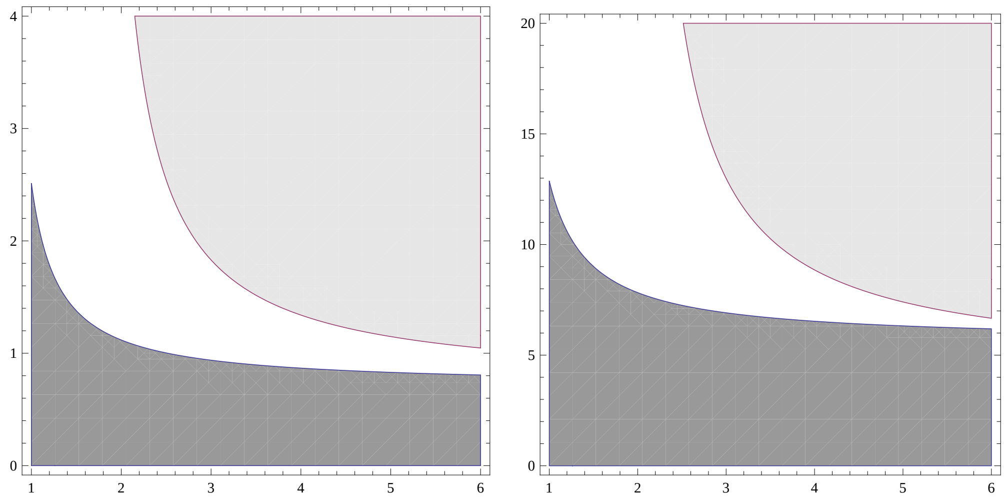
Comparing the investment level, we easily notice that $\phi^*_k \geq \phi^F_k \geq \phi^N_k$. Moreover, $\phi^F_k \geq \phi^P_k$ if and only if

$$\Delta \geq \Delta(\gamma, \underline{k}) = \frac{2\left(\sqrt{(9\underline{k} - 4)^2\gamma^2 + 36(5\underline{k} - 4)\gamma + 36} + 3(3\underline{k} + 4)\gamma + 6\right)}{36\bar{k}\gamma - 9\underline{k} + 16\gamma + 36}$$

Then Proposition 1 still holds qualitatively.
When k becomes large, country 2 prefers regime P only for very large γ (i.e., the intensity of demand in the South needs to be several times larger than that in the North). Similarly, country 1 prefers regime F only for very high values of γ. Figure 3 illustrates these points through two examples. In the first panel $\underline{k} = 3$ (which implies that $k_1 = 3\alpha$), and in the second panel $\underline{k} = 10$ (i.e., $k_1 = 10\alpha$). Comparing Figure 2 with the two panels of Figure 3 we can see that the relevant thresholds with respect to γ are shifted upwards when k_1 increases, but the shape of the results is qualitatively similar to the one in the base case. For instance, for $k_1 = 10\alpha$ country 2 would always enforce patents unless its demand is at least five times larger than that in in country 1.

9.2 Non-cumulative innovation: $v_i^P = v_i^N = 1 + max[\phi_1, \phi_2]$

Suppose that in case of imitation, the quality of the good corresponds to the highest of the two innovations, i.e., $v_i^P = v_i^N = 1 + max[\phi_1, \phi_2]$. Then, either



(a) $k_1 = 3\alpha$ (b) $k_1 = 10\alpha$

Figure 3: Welfare difference $W_i^F - W_i^P$. In the dark shaded region $W_2^F - W_2^P > 0$ and in the light shaded region $W_1^F - W_1^P > 0$.

the equilibrium level of investment of firm 1 is higher and $v_i^P = v_i^N = 1+\phi_1$, or the level of investment of firm 2 is higher and $v_i^P = v_i^N = 1+\phi_2$, or finally $\phi_1 = \phi_2$. In the last case, we can assume that the "winning" invention is ϕ_1 with probability 1/2 and ϕ_2 with probability 1/2.

Under these assumptions and Assumption 1, there always exists an equilibrium where only firm 1 invests and the quality under (N) is:

$$\phi^N = \frac{1}{8}$$

While under (P) it is:

$$\phi^P = \frac{9+4\gamma}{27-32\gamma}$$

These investment levels correspond exactly to the base case when $\Delta \to \infty$ (which implies $\phi_2 \to 0$). Then, when innovation is not cumulative but depends on the maximal developed quality, everything is as in our previous analysis for the case $\Delta \to \infty$.

This equilibrium might not be unique if Δ is very small and γ very large. In the latter case, another equilibrium may exist in which only firm 2 invests. However, this second Nash equilibrium is less realistic because for these values country 2 behaves like an advanced economy.

Proof:

- *Regime N*:

Assume the IPR regime is N and consider a candidate equilibrium in which $\phi_1 > \phi_2$ (first candidate equilibrium). Then, replacing $v_1 = v_2 = 1+\phi_1$ in equation (11) and maximizing the two profits we obtain:

$$\begin{aligned} \phi_1^{I_1} &= \frac{2\alpha}{9k_1 - 2\alpha} \\ \phi_2^{I_1} &= 0 \end{aligned}$$

Replacing the values of ϕ_1 and ϕ_2 in the profit function 11 we have:

$$\begin{aligned} \Pi_1^{I_1} &= \frac{\alpha}{8} \\ \Pi_2^{I_1} &= \frac{9\alpha}{64} \end{aligned}$$

Now consider a candidate equilibrium in which $\phi_2 > \phi_1$. With the same steps one obtains:

$$\begin{aligned} \phi_1^{I_2} &= 0 \\ \phi_2^{I_2} &= \frac{2\alpha}{9k_2 - 2\alpha} \end{aligned}$$

Replacing the values of ϕ_1 and ϕ_2 in the profit function (11) we get:

$$\begin{aligned} \Pi_1^{I_2} &= \frac{9\Delta^2\alpha}{(9\Delta - 1)^2} \\ \Pi_2^{I_2} &= \frac{\Delta\alpha}{9\Delta - 1} \end{aligned}$$

Moreover, if no firm invests, both firms get the Cournot profits:

$$\Pi_1^0 = \Pi_2^0 = \frac{1}{9}\alpha$$

One can first notice that it is never an equilibrium for the two firms to invest. In addition, $\Pi_2^{I_1} > \Pi_2^{I_2}$ and $\Pi_1^{I_1} > \Pi_1^{I_2}$ if and only if $\Delta \geq \frac{3+2\sqrt{2}}{3} \simeq 1.94$. Then, for $\Delta \geq \frac{3+2\sqrt{2}}{3}$, the first candidate equilibrium (firm 1 invests, firm 2 does not) is the only equilibrium of the game. The quality of the goods is $v_1 = v_2 = 1 + \phi_1 = 1 + \frac{2\alpha}{9k_1 - 2\alpha}$, which corresponds to the base case for $\Delta \to \infty$.
For $1 \leq \Delta < 1 + \frac{2\sqrt{2}}{3} \simeq 1.94$, the second Nash equilibrium (firm 2

invests, firm 1 does not) can also arise.
Finally, if we consider a candidate equilibrium in which $\phi_1 = \phi_2$, firms maximize the expected profit:

$$E\,\Pi_i = \frac{1}{2}\Pi_i(v_i^N = 1 + \phi_1) + \frac{1}{2}\Pi_i(v_i^N = 1 + \phi_2)$$

It can be easily verified that there is no equilibrium with $\phi_1 = \phi_2$ (when maximizing the expected profit, firm 1 always invests more than firm 2).

- *Regime P*:

Now assume the IPR regime is P and consider a candidate equilibrium in which $\phi_1 > \phi_2$. Then, replacing $v_1 = v_2 = 1 + \phi_1$ in equation (11) and maximizing the two profits we obtain:

$$\phi_1 = \frac{9\alpha_1 + 4\alpha_2}{18k_1 - 9\alpha_1 - 4\alpha_2}$$
$$\phi_2 = 0$$

The profits under assumption 1 can be written as:

$$\Pi_1^{I_1} = \frac{\alpha(9 + 4\gamma)}{27 + 32\gamma}$$
$$\Pi_2^{I_1} = \frac{144\alpha(1 + \gamma)}{(27 + 32\gamma)^2}$$

Now consider a candidate equilibrium in which $\phi_2 > \phi_1$. We have:

$$\phi_1 = 0$$
$$\phi_2 = \frac{2\alpha_2}{9k_2 - 2\alpha_2}$$

The profits are:

$$\Pi_1^{I_1} = \frac{9\Delta^2\alpha(1 + \gamma)(9 + 4\gamma)}{4(9\Delta(1 + \gamma) - \gamma)^2}$$
$$\Pi_2^{I_1} = \frac{\Delta\alpha\gamma}{9\Delta(1 + \gamma) - \gamma}$$

Proceeding as above, we can verify that, for $\gamma \leq \frac{9(5+3\sqrt{17})}{64}$, the only equilibrium is the one in which only firm 1 invests. For $\gamma > \frac{9(5+3\sqrt{17})}{64}$

and $\Delta < \frac{9+4\gamma}{9(9+4\gamma)-3\sqrt{(9+4\gamma)(27+32\gamma))}}$ a second equilibrium exists in which only firm 2 invests. One may notice that $\frac{9(5+3\sqrt{17})}{64} \simeq 2.44$ and $\frac{9+4\gamma}{9(9+4\gamma)-3\sqrt{(9+4\gamma)(27+32\gamma)}} \leq 1 + \frac{2\sqrt{2}}{3} \simeq 1.94$. Then, the second Nash equilibrium can arise only if γ is larger than 2.4 and Δ smaller than 1.94.

Finally, as under regime N there is no equilibrium with $\phi_1 = \phi_2$.

Notice that we have computed the equilibria assuming that firm 2 is not allowed to export in country 1 when the regime is P. If we assume that, when $\phi_2 = \max\{\phi_1, \phi_2\}$ et $\phi_1 = 0$, firm 2 is then allowed to export in country 1 even under P, then the conditions for the second equilibrium to exist are ever more demanding. A necessary condition is $\gamma > 333/32 \simeq 10.4$ and $\Delta \leq \frac{\sqrt{128\gamma^2+396\gamma+243}+12\gamma+27}{12\gamma+162} \leq 1 + \frac{2\sqrt{2}}{3} \simeq 1.94$.

9.3 Illegal imports

Until now, when considering the possibility that firm 2 will imitate, we have restricted our attention to the limit cases of either perfect enforcement in country 1 (regime P) or no enforcement (regime N). However, in practice country 1 might not be able to ban all of the imports by firm 2. We explore this possibility by assuming that if firm 2 imitates, it might manage to (illegally) sell its production, but only with some probability $f \in [0, 1]$. This parameter simply captures the ability of country 1 to enforce IPR by banning illegal imports of imitated goods produced abroad. If $f = 1$, we are in the former regime P and firm 2 cannot export in 1. If $f = 0$ there is no restriction to the import of imitated goods in country 1, and we are in regime N. Under these assumption, the profits of firms 1 and 2 can now be written as:

$$\Pi_1 = (1-f)(a_1(v_1 - b_1(q_{11}+q_{21}))q_{11}) + f(a_1(v_1 - b_1(q_{11}))q_{11}) + p_{12}q_{12} - k_1\frac{\phi_1^2}{2}$$
$$\Pi_2 = (1-f)(a_1(v_2 - b_1(q_{11}+q_{21}))q_{21}) + p_{22}q_{22} - k_2\frac{\phi_2^2}{2}$$

Maximizing these profits we obtain the reaction functions:

$$
\begin{aligned}
\phi_1(\phi_2) &= \frac{2\left(9(1+f)^2\alpha_1+(3+f)^2\alpha_2\right)}{9\left((3+f)^2k-2(1+f)^2\alpha_1\right)-2(3+f)^2\alpha_2}(1+\phi_2) \\
\phi_2(\phi_1) &= \frac{2\left(9(1-f)\alpha_1+(3+f)^2\alpha_2\right)}{9\left((3+f)^2k_2-2(1-f)\alpha_1\right)-2(3+f)^2\alpha_2}(1+\phi_1)
\end{aligned}
$$

Solving the system under assumption 1 we find:

$$
\phi_{1f}^P = \frac{\Delta\left((3+f)^2\gamma+9(f+1)^2\right)}{4\Delta\left(2(3+f)^2\gamma+9f+18\right)+f(9-(6+f)\gamma)-9(1+\gamma)} \tag{48}
$$

$$
\phi_{2f}^P = \frac{(3+f)^2\gamma+9(1-f)}{4\Delta\left(2(3+f)^2\gamma+9f+18\right)+f(9-(6+f)\gamma)-9(1+\gamma)} \tag{49}
$$

$$
\phi_f^P = \frac{\Delta\left((3+f)^2\gamma+9f(f+2)\right)-f(9-(6+f)\gamma)+9(1+\gamma+\Delta)}{4\Delta\left(2(3+f)^2\gamma+9f+18\right)+f(9-(6+f)\gamma)-9(1+\gamma)} \tag{50}
$$

Comparing equations (48) and (49) with (27) and (28) (for $t = 0$), it is easy to verify that the ϕ_{if}^P, $i = 1, 2$ curves lie between ϕ_i^P and ϕ_i^N and they are closer to ϕ_i^N the lower is f. Imperfect enforcement corresponds thus to an intermediate case between N and P. More precisely, when f decreases from $f = 1$, ϕ_{1f}^P decreases from ϕ_1^N to ϕ_1^P and ϕ_{2f}^P increases f from ϕ_1^P to ϕ_1^N. As for the total quality, if $f \geq \frac{3}{7}$, there exists a threshold value $\Delta(\gamma, f) > 1$ such that $\phi_f^F \geq \phi_f^P$ if and only if $\Delta > \Delta(\gamma, f)$. Thus the result in proposition 1 still holds. Moreover, ϕ_f^P monotonically decreases with f, which implies that the new threshold $\Delta(\gamma, f)$ decreases when f decreases (i.e., regime F generates a higher level of innovation for more admissible values of Δ than in the base case). When $f < \frac{3}{7}$ the threshold $\Delta(\gamma, f)$ becomes smaller than 1, which means that for all admissible values of $\Delta \geq 1$, $\phi_f^P < \phi_f^F$ (i.e., regime F always ensures more innovation than P).

9.4 Imperfect imitation

Until now, we have assumed that firms can fully incorporate the innovation developed by their rival when imitating, i.e., $v_i^N = v_i^P = 1 + \phi_1 + \phi_2$. However, in some cases the imitating firm can only partially reproduce the innovation developed by its competitor. We explore this possibility by assuming that $v_i^N = v_i^P = 1 + \phi_i + g\phi_j$, with $0 \leq g \leq 1$. The reaction functions under (P) become:

$$\phi_1^P(\phi_2) = \frac{2.25\alpha_1(1+g\phi_2)+(2-g)\alpha_2(1+(2g-1)\phi_2)}{4.5k_1-(2.25\alpha_1+(2-g)^2\alpha_2)} \tag{51}$$

$$\phi_2^P(\phi_1) = \frac{(2-g)\alpha_2(1+\phi_1(2g-1))}{4.5k_2-(2-g)^2\alpha_2} \tag{52}$$

And under (N) the reaction function for $i, j = 1, 2$ $j \neq i$ is:

$$\phi_i^N(\phi_j) = \frac{\alpha(2-g)(1+(2g-1)\phi_j)}{4.5k_i-(2-g)^2\alpha} \tag{53}$$

It is easy to check that the investment levels are still strategic complements in all cases if g is not too small (i.e., $g > 1/2$ is a sufficient condition for $\frac{\partial\phi_i^r(\phi_j)}{\partial\phi_j} > 0$ for all $i, j = 1, 2$ $j \neq i$ $r = N, P$). When $g \in (0.5, 1]$ the reaction functions are qualitatively similar to the ones in the base case. We focus on this case to check the impact of imperfect imitation on our base results. Solving the systems of reaction functions we obtain:

$$\phi_{1g}^P = \frac{3k\Delta(9\alpha_1+4(2-g)\alpha_2)-4(2-g)(1-g)\alpha_2(3\alpha_1+2(2-g)\alpha_2)}{54k^2\Delta-3k\left(4(2-g)^2\alpha_2(\Delta+1)+9\alpha_1\Delta\right)-4(2-g)(1-g)(g+1)\alpha_2(3\alpha_1-2(2-g)\alpha_2)} \tag{54}$$

$$\phi_{2g}^P = \frac{4(2-g)\alpha_2((1-g)(3\alpha_1+2(2-g)\alpha_2)+3k)}{54k^2\Delta-3k\left(4(2-g)^2\alpha_2(\Delta+1)+9\alpha_1\Delta\right)-4(2-g)(1-g)(g+1)\alpha_2(3\alpha_1-2(2-g)\alpha_2)} \tag{55}$$

Then, adding these two values, under assumption 1 we have:

$$\phi_g^P = \frac{3\Delta(\gamma+1)(4(2-g)\gamma+9)-6\left(g^3-5g+2\right)\gamma-4\left(4-g^4+4g^3-10g\right)\gamma^2}{2(2-g)\gamma(3((2-g)g-3)-2(2-g)(g^2+2)\gamma)+3\Delta(\gamma+1)(4(5-g)(g+1)\gamma+27)} \tag{56}$$

Similarly, under regime N we obtain for $i = 1, 2$:

$$\phi_{ig}^N = \frac{2(2-g)\alpha(3k\Delta-2(2-g)(1-g)\alpha)}{4\left(g^2-1\right)(g-2)^2\alpha^2+6(g-2)^2k(\Delta+1)\alpha-27k^2\Delta} \tag{57}$$

Under assumption 1 $\phi_g^N = \phi_{1g}^N + \phi_{2g}^N$ is:

$$\phi_g^N = \frac{3(2-g)\Delta-4+10g+g^4-4g^3}{3(5-g)(g+1)\Delta-(2-g)^2\left(g^2+2\right)} \tag{58}$$

When $g = 1$ it is easy to check that the investment levels are those of the base case. Since everything is continuous we deduce that when g is sufficiently close to 1, all the base results are preserved. For $g \in (0.5, 1)$, the investments expressions (56) and (58) are quite complex. We conduct the comparison of the investment levels by way of simulations. They reveal

that having $g < 1$ reduces the free-riding problem posed by imitation. The innovation levels of the two firms under regimes P and N increase (more for firm 1 which is more efficient) with respect to the base case, as well as the total level of innovation when g decreases. This pushes the optimal threshold of proposition 1 up (i.e., the new threshold $\Delta(\gamma, g)$ increases when g decreases), but the result in proposition 1 is not qualitatively affected. For instance, for $g = 1/2$ the threshold value $\Delta(\gamma)$ lies between 1.15 and 4/3 (instead of between 1 and 4/3 as in proposition 1).
Then when imitation becomes less perfect, the partial protection regime P is conducive of more innovation than the full protection regime F in more cases. However, the lower g becomes, the less country 2 will be interested in imitating the innovations of country 1. Country 2 prefers regime F more often when g decreases.[25]

9.5 Cooperative R&D and cross-licensing

When IPR are strongly protected, firms might decide to share their innovations through R&D cooperation in order to share the costs and the benefits of each other's discoveries without illegally imitating. The most complete form of cooperation is a research joint venture, in which firms form a common lab and jointly invest in order to maximize joint profits. In practice, this form of cooperation is not always feasible because of transaction costs, moral hazard and adverse selection problems. R&D cooperation contracts are not easy to draw up and enforce, and are therefore incomplete. Moreover, R&D cooperation between competitors (i.e., firms producing substitute goods) can be undermined if firms are not able to collude downstream (see Scotchmer, 1991 for a discussion of this point and a survey of the theoretical literature). Indeed, the empirical literature shows that research joint ventures are more common when goods are complementary and innovating firms do not compete directly in the downstream

[25] To see this point consider the limit case where g is close to zero. The total level of innovation of firm 2 ($\phi_2 + g\phi_1$) approaches ϕ_2, as under regime F. However, contrary to case F, if the firm imitates it is not able to sell its production in Country 1. There is no benefit to country 2's imitating.

market (see Silipo, 2008). Our paper does not consider such joint ventures and concentrates on competing research programs (or possibly competing joint ventures, based in countries with different levels of development).
As an alternative to research joint ventures, firms may also choose to share innovation with weaker forms of cooperation, such as cross-licensing. Various forms of agreements are possible: fixed fees, royalty-based tariffs or a mix of the two (the main results in the literature are illustrated in Kamien, 1992, and Sen, 2005). In our framework, cross-licensing could allow firms to share the costs of R&D, which might be advantageous because the R&D technology is convex, but also eliminates the competitive advantage of making the innovation for firm 1. This competitive advantage is also challenged by imitation, but in the case of illegal imitation firm 1 would be protected at least in country 1. Although a full treatment of this issue is out of the scope of the present paper, cross-licensing would not generally change the results of the paper. To see this, consider for simplicity a fixed-fee contract under which firms would license their innovations to each other (we denote this case, in which firms can write licensing contracts, as L). The fixed fee would not distort the incentives to innovate nor the market share, and firms would thus choose the same levels of innovation as under regime N ($\phi_i^L = \phi_i^N$), while the fixed fee allows them to share the benefits of cumulative innovation. Now consider the case in which country 2 prefers regime F to regime P (see proposition 2 and figure 1). In this case, country 2 respects IPR in order to access the market of Country 1 and firms do not benefit from cumulative innovation. However, firms might prefer to write a licensing contract to share the benefits of cumulative innovation. Comparing the profit of the two firms in case L and F we obtain:

$$\Pi_1^L - \Pi_1^F = \left[\frac{8\Delta^2}{(8\Delta-1)^2} - \frac{5(3\Delta-2)^2}{(15\Delta-8)^2} - \right]\alpha \tag{59}$$

$$\Pi_2^L - \Pi_2^F = \Delta\left[\frac{9\Delta-1}{(8\Delta-1)^2} - \frac{9\Delta-4}{(15\Delta-8)^2}\right]\alpha > 0 \tag{60}$$

From equations (59) and (60), we see that for $\Delta \leq \Delta_L \simeq 1.5$ both firms prefers L to F. For higher values of Δ firm 2 always prefers L, while firm 1 would prefer F in the absence of compensation. However, the total industry profits are larger under L, i.e.:

$$(\Pi_1^L + \Pi_2^L) - (\Pi_1^F < \Pi_2^F) = \frac{(\Delta(\Delta(\Delta(369\Delta + 655) - 1030) + 320) - 20)\,\alpha}{(120\Delta^2 - 79\Delta + 8)^2} > 0 \tag{61}$$

which implies that the gains of firm 2 when the innovations are shared as in regime N are larger than the losses of firm 1, if any. Then, it is always possible to find a licensing contract (a transfer from firm 2 to firm 1 to compensate the losses of firm 1) which improves the situation for both firms as respect to the no-licensing case.

One might ask if firms would be tempted to use these licencing contracts also in the case in which country 2 prefers regime P to regime F (see proposition 2 and figure 1). In this case, firms 1 and 2 would react to regime P signing a licensing contract establishing that firm 2 can legally imitate (instead of illegally) and thus export in country 1 in exchange for a licence fee paid to firm 1. However, when regime P is preferred by country 2, this kind of contract is not feasible. To see this, compare the profits of the firms under regimes P and L: we easily see that firm 1 would prefer not to licence and stay in regime P, while firm 2 would always prefer to pay to get a licence as in regime L:

$$\begin{aligned}
\Pi_1^L - \Pi_1^P &= -\frac{9\Delta^2\alpha_1(1+\gamma)(8\Delta(5\Delta-2)(27+32\gamma)+27+44\gamma)}{(8\Delta-1)^2(\Delta(27+32\gamma)-4\gamma)^2} < 0 \\
\Pi_2^L - \Pi_1^P &= \frac{9\Delta^2\alpha_1(1+\gamma)(8(1+\Delta(88\Delta-19))\gamma+81\Delta(9\Delta-1))}{(8\Delta-1)^2(\Delta(27+32\gamma)-4\gamma)^2} > 0
\end{aligned}$$

In addition, the total industry profits are larger under P, i.e.:

$$(\Pi_1^P + \Pi_2^P) - (\Pi_1^N < \Pi_2^N) = \frac{81\Delta^2\alpha_1(1+\gamma)(8(8\Delta-5)\Delta\gamma+39(\Delta-1)x+3+4\gamma)}{(8\Delta-1)^2(\Delta(27+32\gamma)-4\gamma)^2} > 0 \tag{62}$$

which implies that the gains of firm 2 when the innovations are shared as in regime N are smaller than the losses of firm 1. Then, even if they were able to write and enforce a contract to share the benefits of incremental innovation, firms cannot agree on such a contract.

Considering a more complex tarif structure is not likely to change these main findings. The conclusion is that cross-licensing may arise in the cases in which country 2 is relatively small and is thus willing to protect IPR in order to access country 1's market. Cross licensing would increase welfare in the two countries with respect to the base case. However, cross licensing would not arise when country 2 prefers a partial protection regime. Thus, the welfare comparisons are not qualitatively affected by the possibility of cross-licensing.

10 Empirical specification

10.1 Foreign market access construction

In the text we argue that market size can be proxied by GDP and we want to assess the impact of internal and external market sizes. As discussed in Section 4.2 and appendix 8.2, the existence of transportation costs does not alter the main insights of the model, but interacts with the (relative) size of the foreign market in determining the quantitative impact of the IPR regime choice. We thus incorporate the role of transportation costs in our measure of the size of foreign demand. In order to take into account the foreign component, we need a measure with which to weight each potential destination market by their accessibility. In particular, F-ALPHA $= \sum_{j \neq i} GDP_j \hat{\phi}_{ij}$, where $\hat{\phi}_{ij}$ is a weight specific to the relationship between countries i and j. We use a trade gravity equation (see Head and Mayer, 2004 and Redding and Venables, 2004) to obtain these weights for each year of our sample. The gravity equation relates bilateral trade flows to variables that are supposed to deter (e.g., distance among partners) or favor (e.g., common language) economic exchanges. Of course, these are not the only components of trade costs. There are also variables specific to the exporter or the importer, like institutional quality or landlocked status. To focus on the bilateral component, we include exporter and importer fixed effects to control for these country-specific variables. The bilateral variables that we consider are bilateral distance (in log), and dummies equaling one if the partners shares a common language or border and if one of the countries was a colonizer of the other. All these explanatory variables are available from the CEPII Gravity Dataset. Bilateral trade data is from BACI-COMTRADE, which provides detailed information on trade flows for manufacturing, agricultural products and raw materials. We concentrate our analysis on the manufacturing trade,[26] as do most of the empirical studies on market access and innovation. As expected, the coefficient for distance is negative and the coefficients for common language, border and colonial past are positive (regressions available on request). Using the coefficients of the bilateral variables we predict the trade costs for each pair of partners.

10.2 Choice of instruments

The first instrument is a measure of technological adoption and diffusion, namely, the lagged number of tractors in neighboring countries (in log). We focus on neighboring countries instead of data on the home country because the diffusion process might be endogeneous to the choice of a broader set of public policies, including enforcement of IPR. Among similar indices, we choose the tractor variable for several reasons. First of all it is a relatively old innovation in a traditional sector which is the focus of policy makers in developing countries. Since tractors are generally used with other inputs such as certified seeds and fertilizers, this may have stimulated the enforcement of IPR in countries that wanted to take advantage of the potential increase in agricultural productivity implied by mechanization. Second, from a statistical point of view this instrument offers several advantages. It provides for important variation not only in the spatial dimension but also in the temporal one. It has, for instance, been shown that in the United States tractor diffusion took several decades (Manuelli and Seshadri, 2003). The good data availability allows us to introduce the instrument lagged by 3 periods (15 years) to reduce endogeneity concerns. It is also in order to limit endogeneity problems that we only use information on neighbors and do not include the country itself. We use the bilateral distances as weights to generate a single indicator for each country and each period (i.e., for each country we add the number of its neighbors' tractors weighted by the bilateral distance from these countries). The information is provided by Comin and Hobijn (2009) in their Cross-country Historical Adoption of

[26]CEPII developed a dataset based on BACI-COMTRADE called TRADEPROD, specifically for the manufacturing sector. This is the version we use. De Sousa et al. (2012) describe the dataset in detail and make it available through the CEPII website.

Technology (CHAT) dataset.

The second instrument is the number of students from the neighbor countries studying abroad. As for tractors, we only use information about neighbor countries to reduce endogeneity. Several versions of this instrument are available in the dataset proposed by Spilimbergo (2009), which contains data about total student flows as well as flows to particular groups of countries (e.g., students going to democratic versus non-democratic countries). We tested several versions of the students flows proposed in the dataset, as well as different techniques of spatial aggregation (using alternatively weighted distances or contiguity dummies). We have retained the best instruments both in terms of exogeneity and relevance, which correspond to the variables *Students* and $Students(FH)$ described in Section 6.2. All alternative specifications give very similar results but they are more exposed to weak-instrument problems (tested using the Kleibergen-Paap statistic). To avoid the related biases, we retain the presented specifications, and alternative specifications and related tests are available upon request.

10.3 Inside-the-frontier innovation

Detecting export discoveries requires a strict set of criteria to avoid the inclusion of temporary exports not really reflecting a new product. First, we use the highest possible level of disaggregation of products for the period analyzed. Using BACI-COMTRADE data for the period 1980-2005, the available classification is SITC Rev 2, which allows for 1836 potential product categories. Second, we follow Klinger and Lederman (2009) by considering a threshold of 1 million US dollars (in 2005 constant prices) to assess whether a product is new in the national export basket. Moreover, to be sure that it is a truly new export, we only include products that retain this export level or higher for two consecutive years. It is possible that some exporters in a country will try new products and, incidentally, will surpass this threshold, while, nevertheless, in the next year exports fall to tiny levels. Consequently, to have a reasonable window of time for the last year in our study, we consider exports until 2007.