Intellectual Property Rights Protection and Trade*

Emmanuelle Auriol†
Sara Biancini‡ Rodrigo Paillacar§

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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 protect IPR to get access to advanced economies' markets, while large emerging countries tend to free-ride on rich countries' technology to serve their internal demand. Asymmetric protection of IPR, strict in the North and lax in the South, leads in many cases to a higher level of innovation than universal enforcement. An empirical analysis conducted with panel data covering 112 countries and 45 years supports the theoretical predictions.

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†Toulouse School of Economics, emmanuelle.auriol@tse-fr.eu
‡Université de Caen Basse-Normandie, CREM, sara.biancini@unicaen.fr.
§Université de Cergy-Pontoise, THEMA, rodrigo.paillacar@u-cergy.fr.

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 pushed to impose "Western-style" IPR legislation worldwide. 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 is tested with the help of panel data covering 112 countries and 45 years.

The first source of conflicts between developed and developing/emerging countries regarding the TRIPS agreement 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 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).

The second source of conflict is that strong IPR limit 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

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

the top three countries in term of R&D worldwide expenditure are the US, China, and Japan.[2] It is thus not clear that international agreements such as TRIPS will lead to more innovation at the global level. More studies are needed to illuminate the pros and cons of universal enforcement of IPR. In this paper, we build a simple model of trade and IPR protection, from which we derive predictions that we draw upon to conduct an empirical analysis.

We study the impact of different IPR regimes (no protection; partial protection where only the rich country enforces IPR; and full protection) on the investment decisions made by private firms in a two-countries model (developing and developed countries). We focus on incremental innovation: innovation enhances the quality of a vertically differentiated commodity, which is produced in each country by the domestic and the foreign firms 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, including 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 legally 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. From the model we predict a U-shape relationship between patent protection and the size of a country's interior market relative to its export market, that is sustained by the data. The analysis has two steps.

First we establish that the link between protection of IPR and investment is non-monotone: full protection of IPR is not always conducive of a higher level of investment than a partial regime. This result arises because, when technological transfer occurs, innovation by one firm expands the demand of both firms so that the competitor has more incentive to invest in R&D.[3] Our model then predicts that stricter IPR decrease 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. We provide some suggestive empirical evidences that increasing IPR decreases on-the-frontier innovation of resident firms in developing countries, but increases innovation

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

[3] The R&D investment of the two competing firms are strategic complements under a partial protection regime of IPR and there are strategic substitutes under a full protection regime.

of nonresident firms, usually based in developed countries.

Second, we establish that advanced economies are the first to enforce IPR, while the incentives to protect IPR in a developing country are decreasing in the relative size of its domestic market compared to its foreign market. When the size of its national market is large compared to its foreign market, the developing country can afford not to protect IPR, even if this precludes its firms from legally exporting to rich countries (e.g., generic drugs produced without licence in India). The paper thus predicts that small developing countries should be willing to enforce IPR, since IPR protection enhances export opportunities, while large ones should be more reluctant to do so. Using a methodology developed in the new economic geography literature for measuring 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. As far as we know this result is new.

2 Related literature

Chin and Grossman (1991), Diwan and Rodrik (1991) and Deardorff (1992) were the first to study the effect of patent protection in an international context with trade. 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 generally decreases welfare in the South.[4] Helpman (1993) generalizes the main insights of the first contributions in a general equilibrium growth model, in which only the North can invent new goods and the South imitates these innovation at a variable rate. This paper shows that increasing IPR (and thus decreasing the rate of imitation in the South) always enhances innovation in the short run.[5]

[4]A complementary empirical literature focuses on the impact of IPR protection in the South on North–South trade. 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.

[5]However, this is not necessarily true in the long run, because of a general equilibrium effect which can make the cost of capital for Northern firms increase more than profits (thus increasing the cost of financing new innovation in the long run). However, this long-run result is not robust to other model specification (see Grossman, 1993 chapter 12). Helpman (1993) also shows that too much imitation is unambiguously bad for the North, while a little imitation can be welfare enhancing. As in previous literature, increasing IPR always decreases welfare in the South, and, when the rate of imitation by the South is large enough, it increases welfare in the North. However, when the South's initial rate of imitation is small, decreasing it further depresses production and income in the South, thus harming Northern firms through lost export opportunities. This result arises because in Helpman (1993) the South has no other production technology than imitation.

Gancia and Bonfiglioli (2008), who build a Ricardian model in which trade induces specialization following comparative advantages, also find that stronger IPR induce higher innovation. In their model, only the North innovates, but innovations can then be used by firms in the South.[6] Southern firms pay royalties to Northern innovators to an extent that depend on the level of IPR enforcement (when IPR are strongly protected, royalties are higher). When trade is allowed, if the South weakly enforces IPR, Northern innovators have less incentives to produce innovations useful in the sectors for which the South has a competitive advantage: as a result, the South's technological progress slows down, as well as total innovation.

Another interesting and original contribution is Acemoglu et al. (2012). The authors distinguish between innovation and standardization of new products, where standardization consists in adapting an innovation to large scale production. IPR protection increases the cost of standardization, with a non-monotone effect on innovation, growth and welfare. When standardization costs are too low, the economy displays too much standardization and too little innovation, which makes stronger IPR desirable. However, when standardization costs become too high, they prevent technology diffusion and thus reducing these costs through weaker IPR becomes desirable. When comparing open and closed economy, Acemoglu et al. (2012) conclude that North-South trade makes strong IPR more desirable, provided that the size of the South is large enough. As in the previous literature, this result depends on the fact that the South does not innovates.

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. The first important papers here are Lai and Qiu (2003) and Grossman and Lai (2004), which look 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 two papers show that the South has a lower optimal level of protection. Starting from this result, Lai and Qiu (2003) show that the South is also in general worse off if IPR protection is harmonized at the level preferred by the North. In addition, they show that multilateral negotiations, in which the North decreases its trade barriers in exchange for the South increasing IPR protection, can produce collective gains, thus offering theoretical support to the TRIPS agreement. Grossman and Lai (2004) enrich the analysis by offering more general specification of the preferences and the technology (in which differences in technology are

[6]With the exception of Gancia and Bonfiglioli (2008), who base their explanation on a comparative advantage mechanism, most of the literature on IPR and trade concentrates on intra-industry trade.

related to different human capital endowments). They confirm that the South prefers in general a lower level of protection than the North. Moreover, instead of concentrating on a particular case of harmonization (i.e., harmonization at the level of protection chosen by the North at the non-cooperative equilibrium as in Lai and Qiu, 2003), they characterize the efficient harmonization level. They show that, since patent policies are strategic substitutes, the equilibrium level of patent 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. This result is not supportive of the TRIPS agreement.

There are three main findings that emerge from the aforementioned theoretical literature. First, a stricter enforcement of IPR has generally a positive impact on innovation. Second, there is a conflict of interest between the North (which generally gains from stricter enforcement in the South) and the South (which generally loses). Third, the level of IPR protection increases with the level of economic development.[7] The third finding is at odds with the results of the empirical literature which explores the relationship between patent protection and economic development as measured by GDP per capita. In empirical work, Maskus (2000), Braga, Fink, and Sepulveda (2000) and Chen and Puttitanun (2005) have all identified a *U-shape* relationship between IPR stength and per capita income, showing the necessity of further work on this topic.[8]

The present paper focuses on this problem. It explores the relationship between IPR protection and economic development in an open economy. To guide the analysis, we develop a simple model of IPR and trade which combines three main ingredients that are relevant for our empirical analysis.

First, we assume that the South can innovate. In our base case, innovation is incremental so that imitators can build upon the competitor's innovations. We show that when the South develops a relatively efficient R&D system, a partial protection regime (strong in the North and weak in the South) often increases global innovation and welfare as compared to a uniformly strong protection of IPR. This is consistent with the result highlighted by Helpman (1993) that some imitation can be welfare enhancing as

[7]The North protects more because it is the main innovator and has the larger demand for innovative goods. The South has an incentive to free-ride which decreases when the South represents a larger share of total demand. Given that the North is either the unique or the main innovator in this literature, when the share of total demand in the South increases, the temptation to free-ride is reduced because of its adverse effect on the North's innovation.

[8]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.

it increases global demand and hence investment. Symmetrically, in the limit case where innovation is not cumulative, we find that stronger IPR increases the total level of innovation, which is consistent with Chin and Grossman (1991), Diwan and Rodrik (1991), Deardorff (1992), Lai and Qiu (2003), Grossman and Lai (2004), Acemoglu et al. (2012).

Second, we allow the South to export, where the South's ability to trade depends on its willingness to respect IPR. As a result, an imitated Northern firm faces reduced competition at home if the trade of imitated goods is banned. This is a new proposal, as compared to Gancia and Bonfiglioli (2008) where imitation does not prevent trade, and to Diwan and Rodrik (1991), Deardorff (1992), Grossman and Lai (2004), where imitation, carried out by a competitive fringe, dissipates all profits in the region in which the good is imitated, without affecting the competitive environment in the other country.

Third, we allow countries to 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 efficient R&D technology. Compared to the previous literature, this third ingredient is new. Combined with the first two ingredients it has new interesting results.

We show that when the relative size of its internal market is small compared to the export market, the South always prefers to protect IPR to enhance its export opportunities. When the relative size of its internal market is large compared to the export market, the South prefers to free-ride on the North by stealing its innovations. Large developing countries start to protect IPR only when they have developed an efficient R&D system and innovate enough on their own (i.e., when they become rich). Since the rich countries strictly enforce IPR, our results suggest that the willingness to enforce IPR should be U-shaped in the relative size of a country's internal market with respect to its export opportunities. Using gravity models to estimate the export opportunities of a country, we provide sound empirical evidence in support of this prediction.

Another point within the TRIPS controversy concerns the impact of universal IPR 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 empirical 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 in the period 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 increase 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.

Our paper proposes a theoretical explanation for these empirical findings. Moreover we look at the relation between stronger IPR protection and innovation in other sectors than pharmaceutical. We find that stricter IPR protection is negatively correlated with patent activity by Southern firms in the manufacturing sectors of a wide panel of countries. Taken together with the empirical results on pharmaceutical, this gives credibility to the idea that by preventing technological transfers from the North, universal protection of IPR is limiting the development of Southern R&D activities in all sectors.

The remainder of the paper is structured as follows. Section 3 presents the base model. Section 4 computes the R&D investment levels equilibrium under the different IPR regimes. Section 4.1 derives our theoretical result on the impact of IPR protection on innovation. Section 4.2 discusses the robustness of the result to variations in the base case model. The empirical implications of the model are derived in section 5 by decomposing the welfare analysis and the investment levels at the country level, in sections 5.1, 5.2 and in section 5.3 respectively. The data are presented section 5.4 and the empirical validity of the results is assessed in section 5.5. Section 6 concludes.

3 The base 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 7.1). 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 section 5.5, a_j is interpreted as the per capita income and b_j as the *inverse* of the population size of country j. 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 compared to the market of 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, 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.).[9] 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 efficiency of the R&D process in country $i = 1, 2$. Innovation is deterministic: by investing $k_i \frac{\phi_i^2}{2}$ a firm increases the quality of the good from $v_i = 1$ to $v_i = 1 + \phi_i$.[10] Without loss of

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

[10] 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

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 (Cournot game). To keep the exposition simple, we assume that, once an innovation is developed, the production costs are zero.[11] 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 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 can 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.

invested, the same qualitative results would hold.

[11] 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).

Since our focus is upon the innovative activity, we do not detail how firms serve 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 (see Gancia and Bonfiglioli, 2008 for a first analysis of the impact of patent right in a trade context). In our base model, this choice of production allocation is a black box and the related costs are normalized to zero.[12]

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 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 $v_i^F = 1 + \phi_i$ $i, j = 1, 2$.

[12] Appendix 7.2 shows that our results are robust to the existence of export costs. In practice 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).

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 $k_1 > \frac{8}{9}\frac{1+\Delta}{\Delta}\alpha$.[13] A necessary condition to obtain interior solutions in all cases (i.e., for all $\Delta \geq 1$) is that k_1 is larger than $\frac{16}{9}\alpha$. We thus make the following assumption.

Assumption 1 $\qquad k_1 = 2\alpha$

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 as shown in appendix 8.1. 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, $i \neq j$.

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

The level of innovation available to firm i depends on IPR protection. Details of the computations of the different cases is given in Appendix 7.2.

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 $\phi_i^F = \frac{3\frac{k_j}{\alpha}-4}{15\Delta-8}$. 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 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) yields $\phi_i^N = \frac{1}{8\Delta-1}\frac{k_j}{2\alpha}$. 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 :

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

When firm 2 chooses to free-ride on innovation by firm 1 it cannot export in country 1. This restriction breaks the symmetry between the two markets. The total investment level ϕ^P decreases with γ, the relative size of country 2. 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. One could argue that the 'no protection' regime is not relevant because rich countries do enforce IPR, so that, at worst, partial protection holds. This is true, however, only if illegal imports are banned. With smuggling the equilibrium converges towards the no-protection regime. This bad outcome 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.[14]

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 7.2. ■

Contrary to what the proponent of strong IPR argue, it is not always true that stronger protection 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.[15] When only the advanced economy (by convention, country 1) invests in R&D, corresponding in our model to $\Delta \rightarrow \infty$, the second condition of Proposition 1 holds and market integration without

[14] "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).

[15] 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

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. This result is consistent with previous studies focusing on the cases when either only the North innovate (see Chin and Grossman, 1991, Diwan and Rodrik, 1991, Deardorff, 1992, Acemoglu et al., 2012), or the south innovative capacity is weak compared to the North (see Lai and Qiu, 2003, Grossman and Lai, 2004).

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 has been 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.[16] This equilibrium does not militate for universally strong protection of IPR.

Third, the threshold value $\Delta(\gamma)$ decreases with the ratio γ. Intuitively, for a given size of the total market α (i.e., total GDP), when the relative size of the southern market is small, the free-riding problem is 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 the developing country market is large, free-riding by firm 2 has a strong 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 7.6 we also show that the asymmetric IPR regime P is often the globally optimal utilitarian policy.

[16] 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).

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 base 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 7.2 we assume that selling in a foreign country implies a unit cost equal to $t \geq 0$ (e.g., an export 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 8.1 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. Nevertheless, in some cases innovation is not cumulative. In appendix 8.2 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 implies that stricter protection 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 consistent with results by Chin and Grossman (1991), Diwan and Rodrik (1991), Deardorff (1992), Lai and Qiu (2003), Grossman and Lai (2004), and Acemoglu et al. (2012). In their models innovation is not cumulative, so that an increase in the strength of protection always increases innovation.

We explore the possibility of illegal imports in appendix 8.3. We assume that if firm 2 copies firm 1's innovation, firm 2 can smuggle 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).[17]

Appendix 8.4 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 of perfect imitation 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 firms' 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. Indeed when imitation becomes imperfect the negative impact of free riding on Northern imitation and welfare is reduced.[18] This is in line 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).

In the base model, we have assumed that whenever country 2 does not protect innovation (regime P), firm 2 imitates and thus limits its export possibilities. However, if there is no global sanction restricting country 2 from exporting because of its lack of IPR protection, firm 2 might freely choose between becoming an imitator (and thus not exporting in country 1) or respecting patents to be able to export in country 1 (although the home country does not impose it). Appendix 8.5 shows that allowing for this possibility does not change our main insights. When firm 2 decides to imitate, innovation and welfare are as described in the P regime of the base case. When firm 2 decides to respect patents everything is as in regime F. The choice made by firm 2 depends on the comparison of the profits under the two regime P and F. We show that there exists a region of the parameters for which $\Pi_2^F > \Pi_2^P$ while $W_2^F < W_2^P$. In this region, although country 2 does not protect IPR, firm 2 decides not to imitate, in order to be able to

[17] 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).

[18] However, because of trade effects (imitated goods cannot be exported in the North), the South chooses also to imitate less often when imitation is imperfect (i.e. it is more willing to enforce IPR).

export to country 1. In this region welfare under P is the same as under F so that the government is indifferent between enforcing and not enforcing IPR (and would prefer not to enforce it if enforcing generates a small fixed cost). Our qualitative conclusions are not affected although there is now a region of indifference in which the preference of country 2 for regime P becomes weak.

Appendix 8.6 explores the possibility that under regime P firm 2 patents its innovation in country 1 (which protects patents), thus avoiding imitation from firm 1, and simultaneously incorporates firm 1 innovation in its own product designed for its domestic market. This implies that under regime P the quality of the good produced by firm 1 is $1 + \phi_1$ and the quality of the good produced by firm 2 is $1 + \phi_1 + \phi_2$. When firm 1 cannot free-ride on the investment by firm 2, which on the contrary is copying the innovation of firm 1, firm 1 reduces its investment. By contrast firm 2 invests more than in the base case, so that globally investment increases. Our qualitative results on innovation and welfare are preserved. In particular, Proposition 1 still holds, but the critical threshold value $\Delta(\gamma)$ is pushed up.

This section has shown that our base result is robust to different variations of the model. We need now to decompose the result of Proposition 1, which is at the aggregate (world) level, at the country level, for the purpose of the empirical analysis.

5 Empirical implications

This section studies country willingness to protect IPR, and decomposes the impact of IPR protection on innovation in poor and rich countries.

5.1 IPR protection

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. Appendix 8.7 provides a theoretical justification for the rich countries first mover behavior: the rich country always wins to move from N to P, while this is not true for the poor country. 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 7.3. ■

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 something, with considerable heterogeneity between domestic firms (only 15.7%-20% are exporting) and foreign-owned ones (60.8%-64.1% are exporters).

From an empirical point of view, we expect the strength of protection 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. Poor countries with a small interior market compared to their export opportunities should enforce IPR relatively strictly. At the other end of the spectrum, advanced economies are also enforcing strictly IPR, and in fact have been the first to willingly do so. In the middle, we expect developing countries with large populations, and hence large internal market compared to their export opportunities, to free ride on rich countries' innovations by adopting a weak enforcement of IPR.

5.2 Conflicts over IPR protection

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 7.4. ■

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.

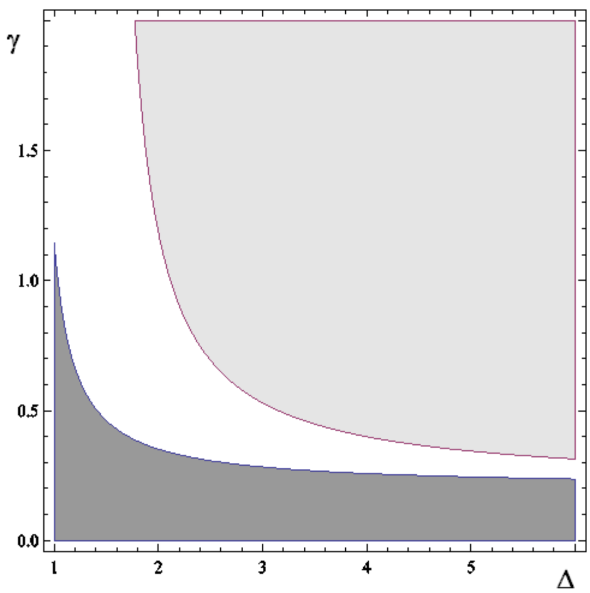

Figure 1: Welfare difference $W_i^F - W_i^P$. In the dark shaded region $W_2^F - W_2^P > 0$ and in the light shaded region $W_1^F - W_1^P > 0$.

Contrary to the developing country, country 1 prefers regime P whenever γ or Δ are small enough. It prefers full protection F otherwise (see Appendix 7.6 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, its 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 huge interior market, and later to serve also 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), to reach 5 percent today. 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.[19]

5.3 IPR and innovation in poor countries

We decompose the result of Proposition 1 at the country level to assess the impact of the strength of IPR protection 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 7.5 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 $v_1^F = 1 + \phi_1^F$.

[19] 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.

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

- $\phi^F_{1d} \geq \phi^P_1 \Leftrightarrow d \geq \tilde{d}$
- $\phi^F_{2d} \leq \phi^P_2 \Leftrightarrow d \geq \hat{d}$

Proof. For proof, see Appendix 7.5. ■

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^F_{d1} is always larger than ϕ^P_1. Since most developing countries are either doing no R&D (i.e., $\Delta \rightarrow +\infty$) 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, innovation by local firms should decrease.

5.4 The data

To empirically test the 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.[20] This source 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).

We measure innovation by the number of patent applications from domestic and foreign firms resident in a country. This information is provided by the World Bank

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

(World Development Indicators). This is a proxy for the discovery of new (enhanced) products.

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.

5.5 Empirical results

Our model predicts that developing countries with a small internal market relative to their trade partners prefer to protect patent rights, while those with a relative larger internal market are more reluctant to protect them. Moreover, rich countries strictly enforce IPR, so the first empirical implication of the model is that the strength of patent protection is a U-shaped 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-shaped function of the size of the national market and an inverted U-shaped function of the size of the foreign market. An empirical challenge is to find a good proxy for a country's export opportunities. We use a methodology developed in the new economic geography literature (see Head and Mayer, 2004, and Redding and Venables, 2004) to compute this proxy, as explained below. The results of the regressions are presented in Table 1. We fully exploit the panel dimension of our database, including in all regressions country fixed effects and time effects. Standard errors are robust and clustered by country. Continuous variables are in logs.

To test the model prediction we use the information about per capita GDP ($GDPPC$) and population (POP). $GDPPC$ is the per capita GDP at constant 2005 prices, computed at purchasing power parity (the full series is provided in the World Development Indicators). 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 (see Appendix 7.1). We thus define the empirical equivalent of α_i as $ALPHA = GDPPC * POP$. To avoid, as far as possible, residual endogeneity problems, the variables describing the market size are lagged by one period (i.e., 5 years).[21]

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

[21] 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 5 years. This specification is based on the implications of our theoretical model and on the empirical literature on IPR (e.g., Ginarte and Park, 1997; Maskus, 2000; Chen and Puttitanun, 2005).

the coefficient of $ALPHA^2$ to be positive, which is confirmed by the estimation. We also include, in this as in all the following regression, additional controls, namely an economic freedom index, $freedom$, and a dummy indicating the year of entry into the GATT, or, later, the WTO, $gatt/wto$. Intuitively, these two variables, $freedom$ and $gatt/wto$, should positively influence the level of IPR protection. 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. We have also performed the same regression without the controls $freedom$ and $gatt/wto$, to be able to consider a larger time span, covering the period 1965–2005 for which the controls are not available. This allows us to consider a larger unbalanced panel of 118 countries and 906 observations. We have obtained very similar and significant coefficients for both $ALPHA$ and $ALPHA^2$. The same results are obtained if if we restrict the analysis to a balanced panel of 79 countries, covering the period 1965–2005.[22] This first result is consistent with the empirical findings of Maskus (2000), Braga, Fink, and Sepulveda (2000) and Chen and Puttitanun (2005), that IPR enforcement is U-shaped with respect to per-capita income.

In column (b) we add a measure of the foreign market size, which is a proxy for α_j. This measure of the foreign market potential, denoted $F - ALPHA$, is a weighted sum of the size of the foreign markets of the trade partners. The weights given to each partner take into account the existence of trade costs. Our empirical methodology thus includes a measure of exportation costs, weighting each potential destination market by their accessibility.[23] To be more specific, we define

$$F - ALPHA_i = \sum_{j \neq i} GDP_j \hat{\Phi}_{ij}, \tag{12}$$

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 between trade partners. In our analysis we include bilateral distance (in log), and dummies equaling one if the partners share a

[22] In this case, due to data limitations and in order to be able to get the larger possible sample, we use data on GDP at constant 2005 prices, not corrected for PPP.

[23] As shown in appendix 7.2, the existence of trade costs does not alter the main insights of the model, but it interacts with the (relative) size of the foreign market in determining the impact of the IPR regime choice.

common language or border and if one of the countries was a colonizer of the other.[24] Of course, these bilateral variables 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. We include exporter and importer fixed effects in the trade equations to control for these country-specific variables. All these explanatory variables are available from the CEPII Gravity Dataset. We concentrate our analysis on manufacturing data.[25] Using the coefficients of the bilateral variables in the gravity equation, we compute the weights $\hat{\Phi}_{ij}$ for each pair of trade partners. Due to data limitations, the regressions including the foreign market potential focus on the period 1985–2005. We expect the coefficient of $F - ALPHA$ and $F - ALPHA^2$ to have opposite signs 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 still significant and of similar size.

The foreign market potential computed above included all the trade partners of a country. Yet in the model, if country 2 does not enforce IPR it faces reduced export opportunities because it trades with country 1, a rich country, which protects IPR. Empirically, we should thus distinguish between trade partners who strongly enforce IPR and those who do not. In other words, the impact of the size of the foreign market should be conditioned on whether the trade partners protect IPR or not. We expect the impact of trading with countries which strictly enforce IPR to be significant, while there should be no effect when trading with countries which do not enforce IPR. To check this prediction, we decompose a country's trade opportunities into different groups based on the strength of IPR protection of the trade partners. In column (c) we replace $F - ALPHA$ with the weighted sum of the GDPs of trade partners which strongly protect IPR at each period (i.e., which have an IPR index in the highest quartile), namely the variable $F - ALPHA - strng$. In column (d) we also include the market size of trade partners with a weak IPR index (i.e., in the three lowest quartiles), namely the variable $F - ALPHA - weak$. The results shows that the impact of the foreign market size is only driven by the countries which strongly protect IPR. The coefficient for the market potential of trade partners with low IPR index is insignificant (and this is also true if we drop $F - ALPHA - strng$ and its square from the regression). We have also performed sensitivity analysis on the definition of countries with "weak" and "strong" protection (considering various alternative thresholds, such as the highest quintile instead

[24]As expected, in the trade equation the coefficient for distance is negative and the coefficients for common language, border and colonial past are positive (regressions available on request).

[25]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.

Table 1: IPR Equation

	(a)	(b)	(c)	(d)
ALPHA	–2.14*	–2.06*	–2.02*	–2.14*
	(1.10)	(1.18)	(1.11)	(1.15)
ALPHA^2	0.05**	0.05**	0.05**	0.05**
	(0.02)	(0.02)	(0.02)	(0.02)
F-ALPHA		2.72**		
		(1.27)		
F-ALPHA^2		–0.06**		
		(0.03)		
F-ALPHA-strg			2.36***	2.36***
			(0.76)	(0.79)
F-ALPHA-strg^2			–0.06***	–0.06***
			(0.02)	(0.02)
F-ALPHA-weak				–1.72
				(1.15)
F-ALPHA-weak^2				0.04
				(0.03)
freedom	0.59*	0.56*	0.57*	0.56*
	(0.31)	(0.31)	(0.31)	(0.31)
gatt/wto	0.45***	0.43***	0.44***	0.41**
	(0.16)	(0.15)	(0.16)	(0.16)
N. of obs	511	511	511	511
N. of countries	112	112	112	112
Within R^2	0.70	0.71	0.71	0.72

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 are lagged one period.

of the quartile, and the top 30%) and all the results in Table 1 are qualitatively preserved (regressions available upon request). Put together, these results imply a U-shaped relationship between IPR protection and the relative size of a country interior market, $GAMMA = (ALPHA)/(F - ALPHA)$. In particular, the effect of the foreign market potential as measured by $F - ALPHA - strng$ appears crucial and highly significant in all our specifications and robustness check. Our analysis hence shows that the measure of the foreign market potential $F - ALPHA$ is important to explain IPR protection at the domestic level, and the result is largely driven by the export opportunities toward countries which strictly enforce IPR. As far as we know, this result, which empirically illuminates the relationship between IPR strength and trade, is new.

To confirm this finding and verify that the shown coefficient are associated with a proper U-shape, we also test directly the hypothesis of existence of a U-shape using the Sasabuchi-test (Sasabuchi, 1980). The test is performed for the specifications in column (c) and (d) of Table 1, testing for the existence of a direct U-shape with respect to $ALPHA$ and of an inverse U-shape with respect to $F - ALPHA - strng$. In both cases the test supports the U-shape hypothesis (i.e. the test does reject the null hypothesis of non-existence of a U-shape).

The second set of testable implications comes from Proposition 4. The theoretical analysis shows that stricter protection 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 problem of endogeneity. We address this problem by instrumenting IPR. This is a first step to go beyong mere correlations with the existing data. The results are consistent with our theoretical results and previous studies on pharmaceutical, and suggest a negative effect of IPR enforcement on innovation in poor countries. This result shows that more empirical work is needed to measure this effect with greater accuracy.

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, as presented in Table 1 columns (a)–(d), 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 a new set of instruments.

The first instrument is a measure of technological adoption and diffusion, namely, the lagged total number of tractors available in the country (in log). Among similar indices of technology diffusion, we choose tractors for two main reasons. First, it is a relatively old innovation in a traditional sector which is likely to be important in developing countries. Since tractors are generally employed with other inputs such as certified seeds and fertilizers, this may have stimulated the adoption of strong 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 presents 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). Nonetheless, the diffusion process is likely to be correlated with the choice of a broader set of public policies (not exclusively IPR protection). As such, it could be correlated with other unobservable variables influencing innovation (thus violating the exclusion restriction from the innovation equation). For this reason, we do not use the number of tractors in the country. Instead we use the diffusion of tractors in neighboring countries. We use the bilateral distances as weights to generate a single indicator for each country and each period: for each country we sum up the number of tractors in neighboring countries, weighted by bilateral distances.[26] The good data availability allows us to introduce the instrument lagged by 3 periods (15 years) to further reduce endogeneity concerns.

The second instrument is the lagged number of students from the neighboring countries studying abroad. We expect migrant students to have an indirect effect on innovation through IPR. This is in line with studies showing that students who spent time abroad can influence the development of institutions in their home country.[27] In addition, student migrations can favor technological transfers by having an impact on the technological gap between the home and foreign countries.[28] Again, to reduce endogeneity concerns, we consider the neighboring countries excluding the home country. Several versions of student migration flows are available in the dataset proposed by Spilimbergo (2009) (e.g., students going to democratic versus non-democratic countries). We have tested several versions, as well as different techniques of aggregation (using alternatively weighted distances or contiguity dummies). All specifications give the same type of results. We have thus retained the best instruments in terms of exogeneity and relevance, which correspond to the variable $Students(FH)$, i.e., the number of students in neighbor-

[26]The information is provided by Comin and Hobijn (2009) in their Cross-country Historical Adoption of Technology (CHAT) dataset.

[27]For instance, Spilimbergo (2009) shows that individuals educated in foreign democratic countries can promote democracy in their home country.

[28]For instance 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 Dominguez Dos 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.

ing countries studying in foreign democratic countries (as defined by Freedom House).[29] The instrument is lagged three periods (i.e., 15 years). The coefficients of the excluded instruments in the first-stage equations explaining IPR are reported in the bottom parts of table 2.

Proposition 4 has implications on the level of investment in R&D and innovation developed autonomously by firms in the developing country. 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.

To test these predictions, we use data on patents as a proxy for innovation. We focus on the subsample of less developed countries (i.e., excluding the highest income quintile)[30] and we measure domestic innovation as the number of patent applications made by resident firms. Symmetrically, innovations made by firms from developed countries are measured by the number of patent applications made by non-resident firms.[31]

In addition to the variables used as controls in the previous regressions, we add the stock of human capital, *hcap*, and its square, as it should have a direct influence on the innovative capacity of the country. The variable *hcap* is the level of human capital computed with the Hall and Jones method using the new series proposed in Barro and Lee (2010). We first show 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 ($Students(FH)$), and the number of tractors in neighboring countries ($tractors$).

The first-stage regressions confirm that the instruments are statistically adequate. The regressions presented in Table 2 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

[29] 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. Alternative specifications and related tests are available upon request.

[30] 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.

[31] 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.

Table 2: Patent Equation

Patent type	Resident	Non-Resid	All	Resident	Non-Resid	All
	(a)	(b)	(c)	(d)	(e)	(f)
ipr	–0.40***	0.13	0.01	–1.15***	0.32*	0.01
	(0.10)	(0.14)	(0.12)	(0.25)	(0.19)	(0.20)
ALPHA	–6.33**	2.20	0.83	–11.11***	3.16	0.88
	(3.01)	(3.88)	(4.42)	(4.06)	(3.89)	(4.15)
ALPHA^2	0.16***	–0.02	0.01	0.25***	–0.04	0.01
	(0.06)	(0.07)	(0.08)	(0.08)	(0.08)	(0.08)
F-ALPHA-strg	–2.42	4.78*	2.59	–1.71	4.71*	2.58
	(1.71)	(2.61)	(2.13)	(2.12)	(2.48)	(1.97)
F-ALPHA-strg^2	0.07	–0.12*	–0.07	0.05	–0.12*	–0.07
	(0.05)	(0.07)	(0.05)	(0.06)	(0.06)	(0.05)
F-ALPHA-weak	2.32	–0.40	0.04	1.13	–0.10	0.05
	(1.55)	(1.99)	(1.46)	(2.19)	(1.95)	(1.38)
F-ALPHA-weak^2	–0.06	0.01	0.00	–0.03	0.00	–0.01
	(0.04)	(0.05)	(0.04)	(0.06)	(0.05)	(0.04)
freedom	0.68**	0.30	0.57**	0.46	0.31	0.57**
	(0.29)	(0.37)	(0.34)	(0.42)	(0.31)	(0.29)
gatt/wto	–0.36	0.22	0.11	–0.05	0.14	0.11
	(0.23)	(0.20)	(0.17)	(0.28)	(0.18)	(0.16)
hcap	5.37***	–0.73	1.02	4.88*	–0.52	1.03
	(1.97)	(1.74)	(1.76)	(2.66)	(1.63)	(1.69)
hcap^2	–0.17*	0.07	–0.01	–0.19	0.07	0.01
	(0.09)	(0.10)	(0.09)	(0.12)	(0.09)	(0.08)
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	0.56	0.31	0.50	–	–	–
Hansen (p-val.)	–	–	–	0.83	0.56	0.60
First-stage regs.:						
Instruments:						
N. of tractors				327.27***	318.18***	327.27***
				(62.88)	(58.90)	(62.88)
Students(FH)				4.45***	4.49***	4.45***
				(1.35)	(1.42)	(1.35)
F (all instr.)	–	–	–	14.88	15.53	14.88
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 are lagged one period. First-stage regressions include all controls shown in Table 1. Instruments are lagged several periods (see the text for details). F-stat is the Angrist and Pischke version.

basically the same coefficients for the IPR variable. All these robustness checks are available upon request.

The results in Table 2 show that increasing IPR strength 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).[32] They also show that failing to correct for endogeneity bias leads to an underestimation of the impact of IPR on innovation activities. The two effects cancel out when the two sets of patents are merged (see the "All" regression). This result contradicts the idea that stronger protection of IPR in developing countries will lead to more patents at the global level. The total number of patents in the countries which enforce IPR more strictly is not affected: there is simply a substitution between domestic and foreign patents. This result is consistent with Kyle and McGahan (2012) who find that the introduction of patents in developing countries has not been followed by more R&D investment in the diseases that are most prevalent there.

These results illuminate the conflict which sets advanced and developing countries in opposition regarding TRIPS and more generally in matters of strong IPR. According to its proponents, a strict enforcement of IPR reduces technological transfer and reverse engineering, which in turn affects the capacity of a country to genuinely innovate. In Appendix 8.8 we explore this channel by looking at the impact of stricter IPR on within-the-frontier innovation (i.e., goods that are new to a country production basket, but have already been discovered in other countries). The regressions show that a stricter protection of IPR reduces within-the-frontier innovation. This last set of results gives credit to the idea that more protection slows down innovation because it makes it harder for the developing countries to close their initial technological gap.

6 Conclusion

The paper contributes to the understanding of the forces that can encourage/discourage innovation at the global level, focusing on two issues: first, the incentives that developing countries might have to protect IPR; second, the impact of their choices on global innovation. It stresses the role of technical development and internal market size relative

[32] The coefficient for IPR in the non-resident patent equation is only significant at 10% level. To test the robustness of this result we have also estimate a second specification including only $F-ALPHA-strng$ and its square but not $F-ALPHA-weak$ (as in column (c) of table 1) and a third one only including $F-ALPHA$ (as in column (b) of table 1). In all these specification, which are less demanding in terms of number of coefficients to estimate, the size of the IPR coefficient is almost unaffected and the significativity is always increased.

to export opportunities. The empirical analysis adds to the theory by identifying the factors that are most relevant in practice.

The analysis shows that the strength of patent protection is a U-shaped function of the relative size of the domestic market with respect to export opportunities. It also shows that the choice of an IPR regime which maximizes global innovation, 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-riders, the global level of investment in R&D is higher under a uniformly strong 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 such that total investment is larger with partial protection of IPR than with universally strong protection. Our empirical results offer support to the main insight of the theoretical analysis. Uniform IPR protection, as opposed to partial protection, seems to be detrimental to innovation (as measured by patent activity) in developing countries, without bringing clear benefits for global R&D activities. One explanation for this result is that stricter IPR protection reduces the ability of countries to close their technological gap. We provide evidence that stricter IPR protection, by blocking imitation and reverse engineering, reduces the quality of domestic goods in developing countries that enforce them.

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7 Appendix:

7.1 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.

7.2 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:

$$\Pi_i^D = p_{i1}q_{i1} + p_{i2}q_{i2} - tq_{ij} - k_i\frac{\phi_i^2}{2} \tag{13}$$

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

$$q_{ij}^D = \frac{2v_i^I - v_{-i}^I}{3b_j} + \frac{2t}{3a_ib_j}\,, \qquad i, -i, j \in \{1,2\}, i \neq -i \tag{14}$$

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 (13) and the quantity formula by (14), the socially optimal level of innovation in country i becomes:

$$\phi_i^* = \frac{\alpha - t\frac{b_1+b_2}{2b_1b_2}}{\frac{9}{8}\frac{k_1k_2}{k_1+k_2} - \alpha}\,\frac{k_j}{k_1+k_2} \tag{15}$$

  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:

$$\phi^* = \frac{4(\Delta+1)}{5\Delta-4} - \frac{t}{\alpha b_1b_2}\frac{2(\Delta+1)}{5\Delta-4} \tag{16}$$

  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 (14) in the profit function, firm i maximizes (13) with respect to ϕ_i, for a given level of ϕ_j, $i \neq j$. Profit maximization gives the reaction function:

$$\phi_i(\phi_j) = \frac{\alpha(1-\phi_j) - \frac{2b_i-b_j}{b_ib_j}t}{2.25k_i - 2\alpha} \tag{17}$$

  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:

$$\phi_i^F = \frac{1}{2} \frac{\alpha(1 - \frac{\alpha}{3k_j})\frac{k_j}{k_1+k_2} - \frac{t}{k_1+k_2}(k_j(\frac{2}{b_j} - \frac{1}{b_i}) - \frac{4\alpha}{3b_j})}{\frac{9}{8}\frac{k_1 k_2}{k_1+k_2} - \alpha(1 - \frac{\alpha}{3\frac{k_1+k_2}{2}})} \tag{18}$$

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:

$$\phi_1^F = \frac{6\Delta - 4}{15\Delta - 8} - \frac{t}{\alpha}\frac{6(\frac{2}{b_2} - \frac{1}{b_1})\Delta - \frac{4}{b_2}}{15\Delta - 8} \tag{19}$$

$$\phi_2^F = \frac{5}{15\Delta - 8} - \frac{t}{\alpha}\frac{(\frac{4}{3b_1} - \frac{1}{b_2})}{15\Delta - 8} \tag{20}$$

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.[33] 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

[33]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.

in transportation costs tends to increase the negative impact 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:

$$\phi_i(\phi_j) = \frac{\alpha(1+\phi_j) - \frac{2b_i - b_j}{b_i b_j}t}{4.5k_i - \alpha} \tag{21}$$

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:

$$\phi_i^N = \frac{\alpha\frac{k_j}{k_1+k_2} - \frac{t}{k_1+k_2}\left(k_j\left(\frac{2}{b_j} - \frac{1}{b_i}\right) - \frac{2}{3}\alpha\left(\frac{1}{b_j} - \frac{1}{b_i}\right)\right)}{4.5\frac{k_1 k_2}{k_1+k_2} - \alpha} \tag{22}$$

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:

$$\phi^N = \phi_1^N + \phi_2^N = \frac{\Delta+1}{8\Delta-1} - \frac{t}{\alpha}\frac{((\frac{1}{b_2}-\frac{2}{b_1})+(\frac{1}{b_1}-\frac{2}{b_2})\Delta)}{8\Delta-1} \tag{23}$$

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 8.3).

- *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 (14). At the first stage, profit maximization gives the reaction functions:

$$\phi_1(\phi_2) = \frac{(1+\phi_j)(2.25\alpha_1+\alpha_2)-\frac{2t}{b_2}}{4.5k_1-(2.25\alpha_1+\alpha_2)} \tag{24}$$

$$\phi_2(\phi_1) = \frac{(1+\phi_1)\alpha_2+\frac{t}{b_2}}{4.5k_2-\alpha_2} \tag{25}$$

In the case of partial protection 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:

$$\phi_1^P = \frac{(2.25\alpha_1+\alpha_2)k_2 - \frac{t}{b_2}(2k_2 - \frac{1}{2}\alpha_1 - \frac{2}{3}\alpha_2)}{4.5k_1k_2 - (2.25\alpha_1+\alpha_2)k_2 - \alpha_2 k_1} \tag{26}$$

$$\phi_2^P = \frac{\alpha_2 k_1 + \frac{t}{b_2}(k_1 - \frac{1}{2}\alpha_1 - \frac{2}{3}\alpha_2)}{4.5k_1k_2 - (2.25\alpha_1+\alpha_2)k_2 - \alpha_2 k_1} \tag{27}$$

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:

$$\phi^P = \frac{9\Delta + 4\gamma(\Delta+1)}{27\Delta + 4\gamma(8\Delta-1)} - \frac{t}{b_2\alpha_1}\frac{8(\Delta-1)}{27\Delta+4\gamma(8\Delta-1)} \tag{28}$$

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 (16), (23), and (28) 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:

$$\frac{\partial(\phi^F - \phi^P)}{\partial\Delta} = 12\left(\frac{12\gamma(\gamma+1)}{(27\Delta+4\gamma(8\Delta-1))^2} + \frac{1}{(15\Delta-8)^2}\right) \geq 0 \tag{29}$$

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 (18)). 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 (18) and (28), 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).

7.3 Proof of Proposition 2

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

$$W_i^F = \frac{1}{18}\left[3\alpha_i\Big(2(1+\phi_i^F)^2 + (\phi_i^F - \phi_j^F)^2\Big) + 2\alpha_j(1 + 2\phi_i^F - \phi_j^F)^2\right] - k_i\frac{(\phi_i^F)^2}{2} \qquad (30)$$

Substituting the investment equilibrium value, (19) and (20) where $t = 0$, welfare under full protection of IPR can be written as:

$$W_2^F = \frac{\alpha(\gamma(\Delta(81\Delta-76)+18)+\Delta(9\Delta-4))}{(\gamma+1)(8-15\Delta)^2} \qquad (31)$$

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

$$W_i^N = \frac{1}{9}(3\alpha_i + \alpha_j)(1 + \phi_1^N + \phi_2^N)^2 - k_i\frac{(\phi_i^N)^2}{2} \qquad (32)$$

Setting $t = 0$ in (22), 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:

$$W_2^N = \frac{\alpha\Delta(\gamma(27\Delta-1)+9\Delta-1)}{(\gamma+1)(1-8\Delta)^2} \tag{33}$$

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

$$W_2^P = \frac{1}{3}\alpha_2(1+\phi_1^P+\phi_2^P)^2 - k_2\frac{(\phi_2^P)^2}{2} \tag{34}$$

Setting $t = 0$ in (26) and (27), 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:

$$W_2^P = \frac{16\alpha\gamma\Delta(27(\gamma+1)\Delta-\gamma)}{(4\gamma(8\Delta-1)+27\Delta)^2} \tag{35}$$

Using (31) and (35), we can write the welfare difference $W_2^F - W_2^P$ as:

$$\frac{W_2^F - W_2^P}{\alpha} = \frac{-16\Delta\gamma(27\Delta(1+\gamma)-\gamma)}{(\Delta(27+32\gamma)-4\gamma)^2} + \frac{\Delta(9\Delta(1+9\gamma)-76\gamma-4)+18\gamma}{(15\Delta-8)^2(1+\gamma)} \tag{36}$$

It is straightforward to check that:

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

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

$$\frac{\partial(W_2^F - W_2^P)}{\partial\Delta} = -\alpha\left(\frac{12\Delta(13\gamma+7)-32-68\gamma}{(15\Delta-8)^3(1+\gamma)} - \frac{16\gamma^2(\Delta(189+184\gamma)-4\gamma)}{(\Delta(27+32\gamma)-4\gamma)^3}\right) \tag{37}$$

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.

7.4 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 (30), and under no protection (N) it is defined as in (32), while under partial protection (P) it is:

$$W_1^P = \frac{1}{72}(27\alpha_1 + 8\alpha_2)(1 + \phi_1^P + \phi_2^P)^2 - k_1\frac{(\phi_1^P)^2}{2} \tag{38}$$

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

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

Under partial protection (P) it is:

$$W_1^P = \frac{\alpha(2\gamma(64\gamma + 279) + 405)\Delta^2}{(4\gamma(8\Delta - 1) + 27\Delta)^2} \tag{40}$$

Finally, under no protection (N) it is:

$$W_1^N = \frac{2\alpha(4\gamma + 13)\Delta^2}{(\gamma+1)(1-8\Delta)^2} \tag{41}$$

Comparing equation (39) with (40) 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,

$$\frac{\partial(W_1^F - W_1^P)}{\partial\Delta} = \frac{4\alpha}{5(\gamma+1)}\left(5\gamma\left(\frac{2(\gamma+1)(2\gamma(64\gamma+279)+405)\Delta}{(4\gamma(8\Delta-1)+27\Delta)^3} + \frac{15(3\Delta-2)}{(15\Delta-8)^3}\right) + \frac{15(9\Delta-7)}{(15\Delta-8)^3}\right) \tag{42}$$

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 $\Delta \geq \Delta_1(\gamma)$.

7.5 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:

$$\phi_{2d}^F = \max\left\{\frac{2-8d}{15\Delta - 8}, 0\right\} \tag{43}$$

and firm 1's investment is:

$$\phi_{1d}^F = \tfrac{6(1+d)\Delta - 4}{15\Delta - 8} \quad if \;\; \phi_{2d}^F > 0; \tag{44}$$

$$\phi_{1d}^F = \tfrac{2}{5}(1+d) \quad otherwise. \tag{45}$$

As intuition suggests, ϕ_{1d}^F increases and ϕ_{2d}^F decreases in d. Comparing equation (43) with (27) 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 (44) with (26) (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.

7.6 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 protection 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 ($\Delta \to \infty$).

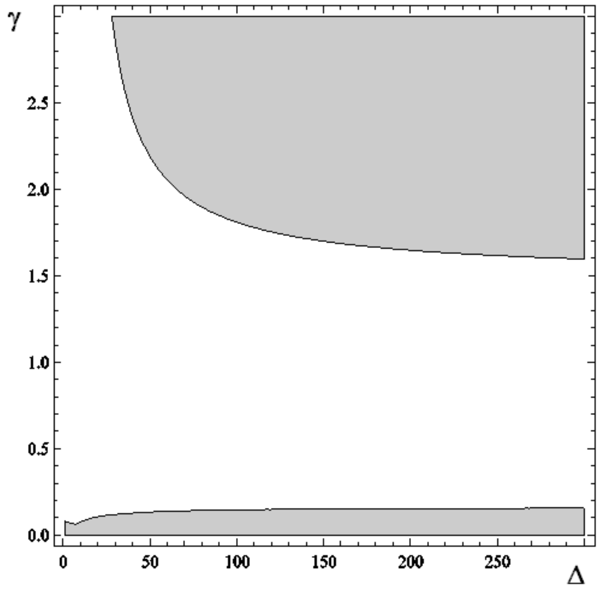


Figure 2: Total welfare difference: $(W_1^F + W_2^F) - (W_1^P + W_2^P)$. In the colored region $(W_1^F + W_2^F) - (W_1^P + W_2^P) > 0$.

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).

8 Robustness checks

8.1 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 (30) and (64)) 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:

$$k_1 = \underline{k}\alpha \tag{46}$$

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

$$\phi_{\underline{k}}^* = \frac{8(\Delta + 1)}{(9\underline{k} - 8)\Delta - 8}$$

$$\phi_{\underline{k}}^F = \frac{4(3\underline{k}\Delta - 4)}{3\underline{k}((9\underline{k} - 8)\Delta - 8) + 16}$$

$$\phi_{\underline{k}}^P = \frac{9\Delta + 4\gamma(\Delta + 1)}{\Delta(18\underline{k}(1 + \gamma) - 4\gamma - 9) - 4\gamma}$$

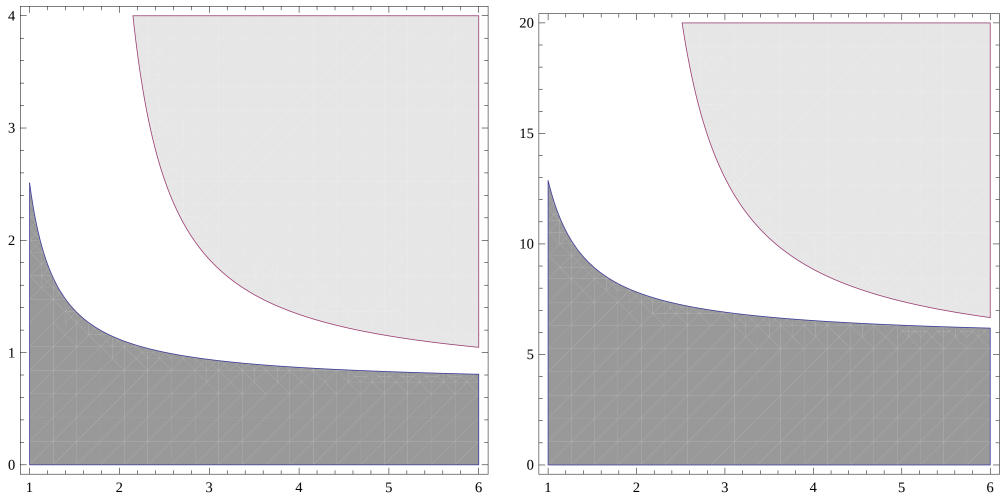
$$\phi_{\underline{k}}^N = \frac{2(\Delta + 1)}{(9\underline{k} - 2)\Delta - 2}$$

Comparing the investment level, we easily notice that $\phi_k^* \geq \phi_k^F \geq \phi_k^N$. Moreover, $\phi_k^F \geq \phi_k^P$ if and only if

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

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.



(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 $W_1^F - W_1^P > 0$.

8.2 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 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:

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

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

$$\Pi_1^{I_1} = \frac{\alpha}{8}$$
$$\Pi_2^{I_1} = \frac{9\alpha}{64}$$

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

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

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

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

  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:

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

The profits under assumption 1 can be written as:

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

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

$$\begin{aligned} \phi_1 &= 0 \\ \phi_2 &= \frac{2\alpha_2}{9k_2 - 2\alpha_2} \end{aligned}$$

The profits are:

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

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 $\Delta \leq \frac{\sqrt{128\gamma^2+396\gamma+243}+12\gamma+27}{12\gamma+162} \leq 1+\frac{2\sqrt{2}}{3} \simeq 1.94$.

8.3 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 protection (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:

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

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:

$$\phi_{1f}^{P}=\frac{\Delta\left((3+f)^2\gamma+9(f+1)^2\right)}{4\Delta\left(2(3+f)^2\gamma+9f+18\right)+f(9-(6+f)\gamma)-9(1+\gamma)} \tag{47}$$

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

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

Comparing equations (47) and (48) with (26) and (27) (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).

8.4 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:

$$\phi_1^P(\phi_2) = \frac{2.25\alpha_1(1+g\phi_2)+(2-g)\alpha_2(1+(2g-1)\phi_2)}{4.5k_1-(2.25\alpha_1+(2-g)^2\alpha_2)} \tag{50}$$

$$\phi_2^P(\phi_1) = \frac{(2-g)\alpha_2(1+\phi_1(2g-1))}{4.5k_2-(2-g)^2\alpha_2} \tag{51}$$

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

$$\phi_i^N(\phi_j)=\frac{\alpha(2-g)(1+(2g-1)\phi_j)}{4.5k_i-(2-g)^2\alpha} \tag{52}$$

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:

$$\phi_{1g}^P = \frac{3k\Delta(9\alpha_1 + 4(2-g)\alpha_2) - 4(2-g)(1-g)\alpha_2(3\alpha_1 + 2(2-g)\alpha_2)}{54k^2\Delta - 3k\left(4(2-g)^2\alpha_2(\Delta+1) + 9\alpha_1\Delta\right) - 4(2-g)(1-g)(g+1)\alpha_2(3\alpha_1 - 2(2-g)\alpha_2)} \tag{53}$$

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

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

$$\phi_g^P = \frac{3\Delta(\gamma+1)(4(2-g)\gamma+9) - 6\left(g^3 - 5g + 2\right)\gamma - 4\left(4 - g^4 + 4g^3 - 10g\right)\gamma^2}{2(2-g)\gamma(3((2-g)g-3) - 2(2-g)(g^2+2)\gamma) + 3\Delta(\gamma+1)(4(5-g)(g+1)\gamma+27)} \tag{55}$$

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

$$\phi_{ig}^N = \frac{2(2-g)\alpha(3k\Delta - 2(2-g)(1-g)\alpha)}{4\left(g^2-1\right)(g-2)^2\alpha^2 + 6(g-2)^2k(\Delta+1)\alpha - 27k^2\Delta} \tag{56}$$

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

$$\phi_g^N = \frac{3(2-g)\Delta - 4 + 10g + g^4 - 4g^3}{3(5-g)(g+1)\Delta - (2-g)^2\left(g^2+2\right)} \tag{57}$$

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 (55) and (57) 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 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.[34]

8.5 Endogenous imitation choice of firm 2

In the base model, we have assumed that whenever country 2 does not protect innovation (regime P), firm 2 imitates and thus limits its export possibilities. However, if there is

[34] 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.

no global sanction restricting country 2 from exporting because of its lack of IPR, firm 2 might freely choose between becoming an imitator (and thus not exporting in country 1) or respecting patents (although the home country does not impose it) to be able to export in country 1. Allowing for this possibility does not change our main insights. When firm 2 decides to imitate, innovation and welfare are as described in the P regime of the base case. When firm 2 decides to respect patents, it will also patent its own innovation in country 1, to avoid imitation from firm 1. In this case, there is no imitation under P (we do not allow here firms to produce two version of the goods, one infringing the competitor's patent, and the other respecting it) and everything is as in regime F.

To understand the imitation choice made by firm 2, we have thus to compare profits under the regime P and F as described in the base case. When the regime chosen by country 2 is P, firm 2 imitates if and only if $\Pi_2^P \geq \Pi_2^F$. The following proposition holds.

Proposition 5 *There are two thresholds* $0 < \underline{\gamma}' < \overline{\gamma}'$ *such that:*

- *If* $0 < \gamma < \underline{\gamma}'$ *then* $\Pi_2^F > \Pi_2^P$*;*
- *If* $\underline{\gamma}' \leq \gamma \leq \overline{\gamma}'$ *then there exists a threshold value* $\Delta_2'(\gamma) \geq 1$ *such that* $\Pi_2^F \geq \Pi_2^P$ *if and only if* $\Delta \leq \Delta_2'(\gamma)$*;*
- *If* $\gamma > \overline{\gamma}'$ *then* $\Pi_2^F < \Pi_2^P$.

Proof: The profits of firm 2 can be written:

$$\Pi_2^F = \frac{\alpha\Delta(9\Delta - 4)}{(15\Delta - 8)^2} \tag{58}$$

$$\Pi_2^P = \frac{\alpha 16\gamma\Delta(9(1+\gamma)\Delta - \gamma)}{(27\Delta + 4\gamma(8\Delta - 1))^2} \tag{59}$$

Comparing equation (58) with (59), it is straightforward to verify that:

$$(\Pi_2^F - \Pi_2^P)|_{\Delta\to 1} = -\alpha\frac{3\,(784\gamma^2 - 168\gamma - 1215)}{49(28\gamma + 27)^2}$$

$$(\Pi_2^F - \Pi_2^P)|_{\Delta\to\infty} = -\alpha\frac{2576\gamma^2 + 1872\gamma - 729}{25(32\gamma + 27)^2}$$

$$\frac{\partial(\Pi_2^F - \Pi_2^P)}{\partial\Delta} = \frac{4}{5}\alpha\left(-\frac{5(21\Delta - 8)}{(15\Delta - 8)^3} + \frac{20\gamma^2(5(8\gamma + 9)\Delta - 4\gamma)}{(27\Delta + 4\gamma(8\Delta - 1))^3}\right) \leq 0$$

The difference $\Pi_2^F - \Pi_2^P$ is decreasing in Δ. Moreover, at the lowest admissible value $\Delta \to 1$, the difference is positive if and only if $\gamma \geq \underline{\gamma}' \simeq 0.28$. At the other extreme $\Delta \to \infty$ is positive if and only if $\gamma \geq \overline{\gamma}' \simeq 1.36$. We deduce that:

- For $\gamma < \underline{\gamma}'$, $\Pi_2^F - \Pi_2^P$ is always positive.

- For $\underline{\gamma}' \leq \gamma \leq \overline{\gamma}'$, $\Pi_2^F - \Pi_2^P$ is positive in $\Delta \to 1$ and negative in $\Delta \to \infty$. Since $\Pi_2^F - \Pi_2^P$ is decreasing, there is a threshold value $\Delta_2'(\gamma) > 0$ such that $\Pi_2^F \geq \Pi_2^P$ if and only if $\Delta \leq \Delta_2'(\gamma)$.
- For $\gamma > \overline{\gamma}'$, $\Pi_2^F - \Pi_2^P$ is always negative.

This proves the result. QED

We can also note that the thresholds $\underline{\gamma}'$, $\overline{\gamma}'$ are higher than the thresholds $\underline{\gamma}$ and $\overline{\gamma}$ in Proposition 2 and $\Delta_2'(\gamma)$ is higher than $\Delta_2(\gamma)$. This implies that the region in which firm 2 prefers to respect IPR has the same shape than the dark-shaded region in Figure 1 but the region is larger, i.e. there exist a region of the parameters for which $\Pi_2^F > \Pi_2^P$ while $W_2^F < W_2^P$. In this region, although country 2 does not protect IPR, firm 2 decides not to imitate, in order to be able to export to country 1. Welfare under P is thus the same as under F (the country's decision does not affect the behavior of the national firm). As a consequence, the government is indifferent between enforcing and not enforcing IPR (and would prefer not to enforce if enforcing generates a small fixed cost). The qualitative conclusions drawn from the results in Propositions 2 and 3 and from the discussion of Figure 1 are not affected (although there is now a region of indifference in which the preference of country 2 for regime P becomes weak).

We also note that for intermediate values of γ ($\underline{\gamma}' \leq \gamma \leq \overline{\gamma}'$) the result depends on Δ, the efficiency of R&D. While in the model we just consider one firm and one industry, in practice different industries could differ in their *R&D* performance (some countries might develop one particular R&D sector, like pharmaceutical for instance). In this case, whenever the country chooses P, firms in different industries could behave differently, some of them imitating the North technology and others respecting IPR to export. In the imitating sectors welfare is like the one described in our regime P and in the non-imitating like in our regime F.

8.6 Regime P when only firm 2 imitates

In the main text, we have assumed that under regime P both firms free ride on each other innovation. In particular, this means that the innovation produced by firm 2 is not protected in any of the two countries. This seems natural because firm 2 is infringing protection of the innovation of firm 1 while improving its technology, so that firm 2 could have difficulties in patenting its own incremental innovation. However, it is possible to imagine that firm 2 could patent its piece of innovation ϕ_2 in country 1 (which protects patents), thus avoiding imitation from firm 1, and then chooses to imitate the innovation of firm 1. This would imply that under regime P the quality of the good produced by firm 1 is $1+\phi_1$ and the quality of the good produced by firm 2 is $1+\phi_1+\phi_2$. This scenario is not very plausible because it implies, first, that there is less varieties of the commodity in the advanced economy compared to the developing country, which is plausible (i.e., in developing countries there are both patented and unpatented commodities on sale but not in advanced economies), and second, that the quality available to the consumers is lower in the rich country than in the poor one, which is far less realistic. We nevertheless explore this option to check the robustness of our results to this limit scenario. Under regime P, firm i maximizes its profit $\Pi_i^P = p_{i1}^P q_{i1} + p_{i2}^P q_{i2} - k_i \frac{\phi_i^2}{2}$ where p_{ij}^r, is the price defined in equation (1) for $\{i, j\} = \{1, 2\}$. From the first order conditions of the firms we obtain the reaction functions:

$$\begin{aligned}\phi_1(\phi_2) &= \frac{\alpha_1 + \frac{4}{9}\alpha_2(1-\phi_2)}{2k_1 - \alpha_1 - \frac{4}{9}\alpha_2} \\ \phi_2(\phi_1) &= \frac{\alpha_2(1+\phi_2)}{2.25k_2 - \alpha_2}\end{aligned}$$

Solving the system of reaction functions we obtain the innovation levels:

$$\phi_1^{P\prime} = \frac{(2.25\alpha_1 + \alpha_2)k_2 - 8\alpha_2(3\alpha_1 + 2\alpha_2)}{54k_1k_2 - (2.25\alpha_1 + \alpha_2)k_2 - 48\alpha_2 k_1 - 8\alpha_2(3\alpha_1 + 2\alpha_2)} \tag{60}$$

$$\phi_2^{P\prime} = \frac{2\alpha_2 k_1}{54k_1k_2 - (2.25\alpha_1 + \alpha_2)k_2 - 48\alpha_2 k_1 - 8\alpha_2(3\alpha_1 + 2\alpha_2)} \tag{61}$$

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, $\phi^{P\prime} = \phi_1^{P\prime} + \phi_{2\prime}^{P}$, is:

$$\phi^{P\prime} = \frac{3(1+\gamma)(9+4\gamma)\Delta + 4\gamma(3+4\gamma)}{3(1+\gamma)(27+32\gamma)\Delta - 4\gamma(9+10\gamma)} \tag{62}$$

Comparing (60), (61) and (62) with (26), (27) and (28), we can easily verify that:

$$\begin{aligned}\phi_1^{P\prime} &\leq \phi_1^P \\ \phi_2^{P\prime} &\geq \phi_2^P \\ \phi^{P\prime} &\geq \phi^P\end{aligned}$$

Thus, when firm 1 cannot free ride on the investment of firm 2, which on the contrary is imitating the innovation of firm 1, its investment level is reduced. On the other hand, firm 2 innovates more than in the base case. Globally, total innovation is higher. However, the shape of innovation and welfare level are qualitatively the same. In particular, the result of Proposition 1 still holds, while the critical threshold value $\Delta(\gamma)$ is pushed up (the new threshold $\Delta'(\gamma)$ belongs to the interval the interval $[4/3, 2(16+\sqrt{58})/33]$).

Given these premises, it is not surprising that the welfare analysis is also qualitatively unaffected. Now country 1 would prefer regime P less often (because it suffers of free riding under P without being able to enjoy the innovation produced by firm 2), while country 2 prefers regime P more often. As a result both the light-shadowed and the dark-shadowed regions in Figure 1 are shifted downwards, while the qualitative results are preserved.

8.7 IPR protection choice of country 1

We assume that country 1 always enforces IPR because advanced economies have been the first to adopt strong IPR legislations. However this first mover behavior can easily be generated in our model. Let assume that initially IPR are not protected (i.e., regime N). Country 1 will choose to protect them domestically, hence moving from regime N to regime P. To see this, we use equations (39) and (41) to compute the welfare difference $W_1^P - W_1^N$:

$$\frac{W_1^P - W_1^N}{\alpha} = \Delta^2 \left(\frac{405 + 2\gamma(279 + 64\gamma)}{(\Delta(27 + 32\gamma) - 4\gamma)^2} - \frac{2(13 + 4\gamma)}{(8\Delta - 1)^2(1 + \gamma)} \right) \geq 0 \tag{63}$$

This welfare difference $W_1^P - W_1^N$ is always positive for $\Delta > 1$ and $\gamma > 0$, which means that country 1 gets a positive gain from starting to enforce IPR when country 2 does not. Moreover the welfare gains are increasing in Δ (i.e. $\frac{\partial(W_1^P - W_1^N)}{\partial\Delta} \geq 0$), which means that the higher the technological gap between country 1 and 2, the higher the gains form unilateral protection. This explains why the most developed countries have been the first to adopt IPR. If we consider country 2, we can show that starting from N enforcing IPR unilaterally is not necessarily welfare improving. To see this, we have to compare regime N with a modification of regime P in which the roles of country 1 and 2 are reversed. In this regime, $P2$, when imitation takes place, firm 1, the more efficient, is not allowed to sell in country 2. In this case, the equilibrium innovation levels become:

$$\phi_1^{P2} = \frac{4\Delta}{4\Delta(8 + 9\gamma) - (4 + 9\gamma)}$$
$$\phi_2^{P2} = \frac{4 + 9\gamma}{4\Delta(8 + 9\gamma) - (4 + 9\gamma)}$$
$$\phi^{P2} = \frac{4(\Delta + 1) + 9\gamma}{4\Delta(8 + 9\gamma) - (4 + 9\gamma)}$$

and the welfare functions under partial protection now take the form:

$$W_2^P = \frac{1}{3}\alpha_1(1 + \phi_1^P + \phi_2^P)^2 - k_1\frac{(\phi_2^P)^2}{2} \tag{64}$$

$$W_1^P = \frac{1}{72}(27\alpha_2 + 8\alpha_1)(1 + \phi_1^P + \phi_2^P)^2 - k_2\frac{(\phi_2^P)^2}{2} \tag{65}$$

where as before $\alpha_2 = \gamma\alpha_1$, $k_1 = 2\alpha$ and $k_2 = 2\Delta\alpha$. The welfare difference now writes:

$$\frac{W_2^{P2} - W_2^N}{\alpha} = \Delta\left(\frac{18\Delta(1+\gamma)(8+27\gamma) - (4+9\gamma)^2}{(4\Delta(8+9\gamma) - (4+9\gamma))^2} - \frac{9\Delta(1+3\gamma) - (1+\gamma)}{(8\Delta-1)^2(1+\gamma)}\right) \tag{66}$$

When $\Delta \to 1$ equation (66) converges to (63) and county 2 always prefers regime $P2$ to regime N. When Δ increases, the welfare difference decreases and regime N is preferred to regime $P2$ if and only if $\gamma \geq (\sqrt{1153} - 17)/54 \simeq 0.3$ and:

$$\Delta \geq \frac{(71+81\gamma)\gamma + \sqrt{2(1+\gamma)(8+\gamma)(251+9\gamma)(189\gamma+236)}}{(17+27\gamma)\gamma - 8} \tag{67}$$

W_2^{P2} is always greater than W_2^N if $\gamma \leq (\sqrt{1153} - 17)/54 \simeq 0.3$. When the relative size of country 2 is very small, protecting IPR unilaterally is welfare increasing for country 2. The reasoning here is quite different than in the base case. When the market size of country 2 is small, unilaterally enforcing IPR increases the profits firm 2, without strongly affecting the incentives to innovate of firm 1, which has the more efficient R&D technology. On the contrary, when country 2 becomes larger, regime $P2$ has a negative effect on innovation: firm 1 is now confined into a small market and has less incentive to innovate, because its production cannot be legally sold to the larger market 2. To stimulate innovation, country 2 thus prefers regime N. For $\gamma \geq (\sqrt{1153} - 17)/54$, enforcing IPR unilaterally is welfare increasing for country 2 if and only if Δ is small.

These results would predict the existence an empirical U shape with respect to the relative size of country 2 even when country 1 does not enforce IPR. However, this prediction would not be correct. Contrarily to the base case, not considering the choice of imitation of firm 1 is here with loss of generality. Being the more efficient innovator, firm 1 has less incentives than firm 2 to imitate (and thus being imitated), and would choose more often to respect patents even if country 1 does not protect IPR.

$$\frac{\Pi_1^{P2} - \Pi_1^F}{\alpha} = \frac{5(3\Delta-2)^2}{(15\Delta-8)^2} - \frac{16\Delta^2(8+9\gamma)}{(4\Delta(8+9\gamma8) - (4+9\gamma))^2} \tag{68}$$

This expression is negative for all $\gamma \geq 0$ if $\Delta \geq 1.5$. Thus, for $\Delta \geq 1.5$ firm 1 prefers to respect IPR for all levels of γ, thus in regime $P2$ everything would be equivalent to regime F. However, country 2 always prefers regime N to regime F, i.e. for all $\Delta \geq 1$:

$$\frac{W_2^F - W_2^N}{\alpha} = \frac{\Delta(9\Delta(1+9\gamma) - 76\gamma - 4) + 18\gamma}{(15\Delta - 8)^2(1+\gamma)} - \frac{\Delta(9\Delta(1+3\gamma) - (1+\gamma))}{(8\Delta - 1)^2(1+\gamma)} \leq 0 \quad (69)$$

There is no incentive though to unilaterally enforce IPR for the less efficient country unless $\Delta \leq 1.5$. In other words, with a significant technological gap between the two countries, country 2 would prefer to stick to N rather than to adopt P, while country 1 always prefer the reverse. This situation corresponds to the first periods in our database where only the rich countries were investing in R&D and the technological gap between the South and the North was huge.

8.8 Imitation and inside-the-frontier innovation

Our empirical results suggest that increasing IPR in developing countries has an adverse affect on the level of innovation produced in the country. One explanation for this negative result is that strict protection of IPR does not allow developing country to close their initial technological gap through imitation and reverse engineering. To assess the empirical relevance of this argument, we explore the effect of stricter IPR on "inside-the-frontier" innovation (i.e. goods that are new to a country production basket, but have already been discovered in other countries). To measure "inside-the-frontier" innovations we follow Klinger and Lederman (2009, 2011), who propose export discoveries, i.e., the discovery of products for exports that have been invented abroad but that are new to the country.[35] 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. Measuring export discoveries requires a strict set of criteria to avoid the inclusion of temporary exports not really reflecting the emergence of a new product in the export capabilities of the country. 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 new product has entered the national export basket. Moreover, we only include products that attain this threshold 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 in the

[35] 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.

next years stoping the exportation. To have a reasonable window of time for the last year in our study, we consider exports until 2007.

Proposition 4 predicts that the level of innovation incorporated in the production of the firm in the developing country is higher when the developing country does not enforce IPR. 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: $\phi^P \geq \phi_2^F \geq \phi_{2d}^F \; \forall d \in [0,1]$. We explore empirically this results performing the same exercise as for "on-the-frontier" innovation (see the results presented in Table 2), but using "inside-the-frontier" innovation (discoveries) as the endogenous variable. We also use the same instrumentation strategy to deal with the endogeneity of IPR. We concentrate the analysis on less developed countries, excluding, for each year in our sample, the highest quintile in term of GDP per capita. The results are presented in Table 3.

Fixed effects and time dummies are included in all specifications. 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.[36] 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. 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.

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

Table 3: Discoveries Equation

SAMPLING:	Panel OLS	Panel IV	Neg. Binomial
	(a)	(b)	(c)
ipr	–0.16	–0.52**	–0.16**
	(0.12)	(0.24)	(0.07)
ALPHA	–2.66	–4.25	1.82**
	(2.86)	(2.74)	(0.76)
ALPHA^2	0.05	0.09	–0.04**
	(0.06)	(0.06)	(0.02)
F-ALPHA-strg	–1.99	–2.31	–1.49
	(2.07)	(2.03)	(1.56)
F-ALPHA-strg^2	0.04	0.05	0.04
	(0.05)	(0.05)	(0.04)
F-ALPHA-weak	–2.09	–2.50	–0.32
	(1.69)	(1.65)	(1.39)
F-ALPHA-weak^2	0.05	0.06	0.00
	(0.04)	(0.04)	(0.04)
freedom	0.40	0.44	0.66**
	(0.35)	(0.38)	(0.30)
gatt/wto	–0.02	0.15	0.10
	(0.16)	(0.20)	(0.13)
hcap	4.63**	4.23**	0.88
	(2.02)	(1.74)	(0.64)
hcap^2	–0.20*	–0.20**	–0.03
	(0.11)	(0.10)	(0.03)
IPR Endogenous	No	Yes	No
No. of obs	332	332	332
N. countries	74	74	74
Within R^2	0.73	–	–
Hansen (p-val.)	–	0.67	–
First-stage regs.:			
Instruments:			
Students(FH)		2.41*	
		(1.37)	
N. of tractors		295.65***	
		(51.10)	
F (all instr.)	–	16.76	–
Partial R^2	–	.18	–

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 Table 1. Instruments are lagged three periods. F-stat is the Angrist and Pischke version.