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Universal Intellectual Property Rights: Too much of a good thing?*

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Abstract

Developing countries' incentives to protect intellectual property rights (IPR) are studied in a model of vertical innovation. Enforcing IPR boosts export opportunities to advanced economies but slows down technological transfers and incentives to invest in R&D. Asymmetric protection of IPR, strict in the North and lax in the South, leads in many cases to a higher world level of innovation than universal enforcement. IPR enforcement is U-shaped in the relative size of the export market compared to the domestic one: rich countries and small/poor countries enforce IPR, the former to protect their innovations, the latter to access foreign markets, while large emerging countries free-ride on rich countries' technology to serve their internal demand.

JEL Classification: F12, F13, F15, L13, O31, O34.
Keywords: Intellectual Property Rights, Innovation, Imitation, Duopoly, Developing Countries.

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1 Introduction

There has always been an international dimension to debates on intellectual property rights (IPR); with the integration of the world economy, however, IPR debates have become global. The United States, the European Union, Japan, and other developed countries have actively 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 World Trade Organization (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. As a result of these tensions the enforcement of IPR legislation varies considerably around the world. The present paper proposes a simple theoretical framework in which developing countries' incentive to enforce IPR can be analyzed. The desirability of enforcing IPR equally, everywhere, including in developing countries, can also be assessed.

One source of conflict between developed and developing/emerging countries regarding the TRIPS agreement 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).[2] Having copied technology invented by others, these countries have become major innovators: today the top three countries in term of R&D expenditure are the US, China, and Japan.[3] It is thus not clear that international agreements such as TRIPS will lead to more innovation at the global level. The costs and benefits of universal enforcement of IPR need to be more thoroughly analyzed.

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 –developing and developed– model. We focus on incremental innovation: innovation enhances the quality of a vertically differentiated com-

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

[2] A second source of conflict concerns medical drugs. 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. 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 lobbies such as PhRMA (representing pharmaceutical companies in the US).

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

modity. This corresponds, for instance, to a new generation of mobile/smart phones, or an improvement of an existing drug. Indeed, many new products are incremental improvements on existing ones (Acemoglu et al., 2016).[4] For instance in the pharmaceutical industry, "on average, only about one-third of new-drug applications submitted to the FDA are for new molecular entities. Most of the rest are either for reformulations or incremental modifications of existing drugs..." (see Congressional Budget Office, 2006 pp 15-16). 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 legally export the imitated good to a country that enforces them.

If a WTO member is found guilty of violating its IPR obligations, the complaining government obtains the right to impose trade sanctions in the form of punitive tariffs. There have hence been more than 30 TRIPS-relates disputes since the enactment of the agreement. In many cases the simple threat of sanctions was enough for the parties to find a solution.[5] In other cases sanctions were implemented.[6] In the US, Section 301 and Special 301 of the Trade Act include retaliatory trade sanction against countries violating US intellectual property rights. Harris (2008) mentions several countries targeted by this mechanism in Latin-American (Argentina, Brazil, Chile and Mexico) and in Asia (China, India, South Korea and Thailand).

Even in the absence of trade sanctions, advanced economies monitor their importations to block out goods suspected of infringing intellectual property right. The European Union has enacted a new regulation concerning customs enforcement of intellectual property rights, which came into force on 1 January 2014 (see IP/11/630 and MEMO/11/327). This regulation introduced a decisive change to the procedure for destroying suspicious goods: Such goods can now be destroyed by customs control without the need to initiate a legal proceeding to determine the existence of an infringement of intellectual property rights. In the United States, Customs and Borders Protection similarly targets and seizes imports of counterfeit and pirated goods, and enforces exclusion orders on patent-infringing goods.

Consistently with these national and international legislations and practices, in the model below IPR protection shields the domestic firm from the competition of patent

[4] Acemoglu et al. (2016) study innovation networks. They focus on the cumulative process of innovation in a wide variety of sectors, as it constitutes the bulk of R&D. By contrast genuine break through or drastic innovations are rather rare.

[5] See Fink (2004) for a discussion and https://www.wto.org for the more recent disputes.

[6] For instance, the European Community suspended Generalized System of Preferences benefits for Korean products in 1987 as a response to Korean violations of IPR (see Žigić, 2000).

infringing foreign competitor. There are thus benefits for a firm originating from a country which enforces IPR in competing with a firm originating from a country that does not enforce them: IPR act as a barrier to its competitor entering into its market, and it can copy its competitor's innovations, if any. If the developing country chooses to protect IPR to be able to export then the patented products are imperfect substitutes and the domestic and the foreign firms are competing à la Cournot in both markets. The analysis has two steps.

First we establish that the link between protection of IPR and investment in R&D is non-monotonic: 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 through imitation, innovation by one firm expands the demand of both firms so that the competitor has more incentive to invest in R&D. Technically 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. Our model then predicts that stricter IPR decreases genuine innovation by the local firm in the developing country, while increasing innovation by the firm in the developed country, without necessarily increasing innovation at the global level. This result is consistent with the empirical literature on pharmaceutical (see Chaudhuri et al., 2006, Qian, 2007, Kyle and McGahan, 2012, Williams, 2013).

Second, we establish that 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 to free-ride on advanced economies technologies, even if this precludes some of 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, as illustrated by the recurrent disputes between the US and China, or the US and Brazil. In other words, our model predicts 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. This theoretical result is consistent with existing empirical evidences. Empirically there is a robust U-shaped relation between IPR enforcement and economic development (see Braga et al., 2000, Chen and Puttitanun, 2005 and Auriol et al., 2017).

2 Related literature

The standard economic rationale for patents is to encourage inventors to incur R&D costs by protecting them from imitators. Starting with the seminal work by Nordhaus (1969), a vast literature in Industrial Organization focus on optimal patent design, notably length and breadth, in the context of a closed economy. Moschini and Langinier (2002), Gallini and Scotchmer (2002), Scotchmer (2004) and Hall (2007) provide nice reviews of this literature. In a nutshell IPR are necessary to stimulate invention and new technologies but must be limited in time and scope as they increase the cost of patented commodities and slow down the diffusion of knowledge.

The issue of IPR adoption in an open economy has first been addressed in the trade literature (see for instance, Lai and Qiu, 2003 and Grossman and Lai, 2004). The main focus of this trade literature is the impact of IPR infringement on horizontal innovation (i.e., the creation of a new variety) in two countries -one rich, one poor- models of monopolistic competition. There are three main findings that emerge from this literature. First, there is a conflict of interest between the North (which generally gains from stricter enforcement in the South) and the South (which generally loses). Second, a stricter enforcement of IPR in the South has generally a positive impact on innovation. Third, the level of IPR protection increases monotonically with the level of economic development.[7] The third finding is at odds with the results of the empirical literature.

In empirical work, Braga et al. (2000) and Chen and Puttitanun (2005) have identified a U-shape relationship between patent protection and economic development as measured by GDP per capita. To guide their analysis, 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. Auriol et al. (2017) confirms this U-shape result and shows that it is robust to the introduction of population size (i.e., total GDP). The discrepancy between this robust U-shape relation and the prediction of a monotone relationship between IPR strength and economic development, shows the necessity of further work on this topic.

The trade literature focuses on non-cumulative innovation (i.e., horizontal innovation, typically a new product variety). In this literature, IPR protection guarantees the monopolistic competition profit, while in the absence of protection a competitive fringe

[7] This literature assumes that the North is both the main innovator and the main market so that when the share of total demand in the South increases (i.e., when it becomes richer), its temptation to free-ride is reduced because of its adverse effect on the North's innovation, hence the monotonicity result.

drives profits to zero. There is therefore no strategic interaction in the innovation choices of the firms: either the variable monopolistic competition profit is larger than the sunk cost of creating a new variety, and a firm does it, or it is not and nothing happens. In this paper we add a strategic dimension to R&D choices, by considering that in each innovative sector/variety (there is a continuum of them), there are two competing firms, one in the North and one in the South, selling imperfect substitutes. In a first stage the firms can invest in R&D. They react strategically to the investment choices of the competition because, in a second stage, they compete in quantities in a vertically differentiated duopoly.

Vertical innovation allows us to study incremental innovation in the form of quality improvement (see Motta, 1993, Sutton, 1991, 1997). To make the analysis interesting we assume that consumer utility is quadratic. Di Comite et al. (2014) show that quadratic utilities gives a meaningful representation of vertical differentiation (i.e., different tastes for quality) in international context, distinguishing it from different tastes for varieties. Additional advantage of using quadratic utilities can be linked to the work of Melitz and Ottaviano (2008): these preferences deliver a linear demand function which allows for variable (endogenous) mark-ups that are affected by the intensity of competition and are thus well suited to study imperfect competition, as created by patents and IPR.

We show that when the South develops a relatively efficient R&D system, an asymmetric protection regime (strong in the North and lax in the South) often increases global innovation and welfare as compared to a universally strong protection of IPR. This result is consistent with Chen et al. (2014). These authors show that, when innovation is "continual" (i.e. incremental), stronger IPR are not necessarily conducive of higher innovation. In Chen et al. (2014) innovation necessarily builds on the previous one, so that strong IPR oblige new innovators to share their profits with the first inventors who hold patents on the technology they need. This reduces the incentives to innovate of second generation innovators.

The remainder of the paper is structured as follows. Section 3 presents the base model. Section 4 derives the result on the impact of different IPR protection regimes on R&D investment and discusses the robustness of the result to variations in the model. Section 5 studies countries' incentive to enforce IPR protection. Section 6 concludes.

3 The base model

We consider a two-countries economy with a set S of innovative sectors. In each innovative sector, $s \in S$, a national and a foreign firm produce a vertically differentiated good. The utility of a representative consumer in country $j = 1, 2$ consuming quantities q_{s1j} and q_{s2j} of goods of qualities v_{s1j} and v_{s2j}, is quasi-linear:

$$U_j = w_j + \int_S a_j \left(v_{s1j} q_{s1j} + v_{s2j} q_{s2j} - \frac{(q_{s1j} + q_{s2j})^2}{2} \right) \mathrm{d}s \tag{1}$$

where w_j is the numeraire and a_j is the weight put by the representative consumer on the consumption of innovative products compared to more basic products such as food, housing and energy. In practice this weight increase with individuals' wealth.[8] The representative consumer in country $j = 1, 2$ has an income R_j and maximizes utility U_j under the budget constraint:

$$R_j = w_j + \int_S (p_{s1j} q_{s1j} + p_{s2j} q_{s2j}) \, \mathrm{d}s.$$

We show in Appendix 7.1 that the inverse demand for good $i = 1, 2$ from sector $s \in S$ in country $j = 1, 2$ is:

$$p_{sij} = a_j (v_{si} - b_j (q_{s1j} + q_{s2j})) \tag{2}$$

where exogenous parameters $a_j > 0$ and $b_j > 0$ reflect per capita wealth and the inverse of the population size respectively. Without loss of generality we assume that the advanced economy is country 1 and the developing economy is country 2: $a_1 > a_2$. By contrast there is no natural order for b_1 and b_2: the population size in country 1 might be smaller or larger than in country 2. The parameter $\alpha_j = a_j / b_j$ reflects the intensity of the demand in country j (i.e, its GDP). A parameter which plays an important role in the analysis is the ratio

$$\gamma = \frac{\alpha_2}{\alpha_1} > 0. \tag{3}$$

The ratio γ captures the relative size/intensity of demand in country 2 with respect to demand in country 1.[9]

Since the quasi-linear utility function (1) is additively separable in each of the S components, the demand defined equation (2) for goods in sector $s \in S$ is independent of the demand from other sectors. We can therefore simplify the exposition by dropping the index s in equation (2). In the following all our results are derived *at the sector level*. This is done without any loss of generality. It is then easy to check that $p_{1j} - p_{2j} = (v_1 - v_2) a_j$

[8]The poor of the world allocate a larger share of their income to buy food, energy, housing and transportation services than the rich, who consume more high-tech products and services, such as electronics, pharmaceutical, healthcare, entertainment services. For instance food consumption absorbs close to 50% of household spending in Cameroon, but less than 10% in the US.

[9]A small γ corresponds to a traditional North-South trade relationship, where the developing country is poor such that its internal market is small compared to the internal market of the advanced economy. A large γ corresponds to the new trade relationships as between fast-emerging countries such as China, India or Brazil, with large internal market, and advanced economies.

so that, unless goods 1 and 2 are identical in quality, they are not perfect substitutes. The demand in each sector corresponds to a quality augmented version of the linear demand model for differentiated goods proposed by Singh and Vives (1984).[10]

To study the impact of technological transfers on global R&D we focus on incremental innovation: by investing $k_i \frac{\phi_i^2}{2}$ a firm $i = 1, 2$ increases the quality of its good from $v_i = 1$ to $v_i = 1 + \phi_i$.[11] As in Motta (1993) and 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.). The parameter $k_i > 0$, is an inverse measure of the efficiency of the R&D process in $i = 1, 2$. We assume that firm 1, based in country 1 (i.e., the advanced economy), has the most efficient R&D process.

$$\Delta = \frac{k_2}{k_1} \geq 1 \tag{4}$$

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 and 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 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, after investment, the quality of the good produced by firm $i = 1, 2$ is $v_i^F = 1 + \phi_i$.

2. No protection (N): countries do not protect patents and, after investment, the quality of the good produced by firm $i = 1, 2$ is $v_i^N = 1 + \phi_1 + \phi_2$.

3. Partial protection (P): only country 1 protects innovation and, after investment, the quality of the good produced by firm $i = 1, 2$ is $v_i^P = 1 + \phi_1 + \phi_2$.

If both countries enforce IPR (regime F), imitation is not allowed and each firm privately exploits its R&D output. If nobody protect IPR (regime N) imitation occurs in

[10] Quality augmented versions of the Singh and Vives (1984) model were initially introduced by Sutton (1991, 1997) and later used by Symeonidis (2003). Symeonidis (2003) compares R&D investment in Bertrand and Cournot competition in a model of horizontal differentiation with R&D spillovers. It focuses on symmetric equilibria (i.e. firms have identical technologies and equal levels of innovation).

[11] Since our focus is on the incentive to invest in R&D, we make the assumption that innovation is deterministic as it simplifies the exposition. If innovation was stochastic so that the probability of improving the quality was increasing with the amount invested, the same qualitative results would hold.

both countries. If country 1 protects IPR but not country 2 (regime P), firm 2 produces a commodity infringing upon firm 1 IPR. If it improves the good by investing in R&D, firm 2 cannot claim protection for this marginal improvement. Firm 1 can reproduce the incremental innovation developed by firm 2, if any, and imitation occurs in both countries.[12]

3.2 Choice of quantities

In the second stage of the game, firms compete in quantities (Cournot game). Since our focus is on the innovative activity of the firms, we do not detail how they organize the physical location of production and shipment. This choice is a black-box and the related production costs are normalized to zero.[13] In country 2 firms are in a duopoly configuration in all regimes. In country 1 there are also in a duopoly position in regimes $r = F, N$. In regime P, firm 1 is in a monopoly position at home because firm 2 is unable to export in country 1 when violating the patent rights of firm 1.

Firm i maximizes with respect to (q_{i1}, q_{i2}) 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 (2). The cost of R&D is in brackets because it has been sunk in the first stage.

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

$$q_{ij}^r = \begin{cases} \frac{v_1^P}{2b_1} & \text{if } i = j = 1 \text{ and } r = P; \\ 0 & \text{if } i = 2 \ j = 1 \text{ and } r = P; \\ \frac{2v_i^r - v_{-i}^r}{3b_j} & \text{otherwise.} \end{cases} \tag{5}$$

4 Investment in R&D

As a benchmark case we first compute the optimal investment level from a global utilitarian point of view when the production levels are defined by (5). At the sector level, the welfare of country $j = 1, 2$ is $W_j^r = S_j^r + \Pi_j^r$:

$$W_j^r = a_j(v_1^r q_{1j}^r + v_2^r q_{2j}^r) - a_j b_j \frac{(q_{1j}^r + q_{2j}^r)^2}{2} - k_j \frac{\phi_j^2}{2}. \tag{6}$$

[12]The assumption that firm 1 can copy the innovation of firm 2 under regime P is not essential to our results. It is made for the sake of realism. Since firm 2 is infringing IPR of firm 1 to develop its product, it cannot legally patent its own incremental innovation in country 1. However, if one assume that firm 2 can patent its marginal innovation ϕ_2 in country 1, thus avoiding imitation from firm 1, the qualitative results of the paper are preserved (computations are available from the authors upon request).

[13]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 $a_j v_i$, for the same level of income a_j, 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.

The supranational planner aims to maximize $W_1^r + W_2^r$ with respect to IPR regime and R&D investment. Once the costs of R&D have been sunk, she has no reason to limit innovation diffusion. At the optimum she chooses the no-protection regime N so that, $v_j^* = v_j^N = 1 + \phi_1 + \phi_2$ $j = 1, 2$. Substituting these values in (8) and (6), she maximizes $W_1^* + W_2^* = W_1^N + W_2^N$ with respect to ϕ_j, for $j = 1, 2$. Let $\alpha = \alpha_1 + \alpha_2$ be the depth of the global market (i.e., the total GDP). At the optimum $\phi_j^* = \frac{\alpha(1+\Delta)}{\frac{9}{8}\Delta k_1 - \alpha(1+\Delta)} \frac{k_j}{(1+\Delta)k_1}$, which is defined only if $k_1 > \frac{8}{9}\frac{1+\Delta}{\Delta}\alpha$.[14] A sufficient 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 for ease of notation.

Assumption 1 $k_1 = 2\alpha$

This normalization is not crucial for our results.[15] What matters is that $\Delta = \frac{k_2}{k_1}$, the technological gap between the two countries, varies. Under assumption 1 the optimal level of investment, $\phi^* = \phi_1^* + \phi_2^*$, is:

$$\phi^* = \frac{4(\Delta + 1)}{5\Delta - 4}. \tag{7}$$

The function ϕ^* is decreasing and convex in $\Delta \geq 1$. The international optimal investment in R&D decreases with the technological gap between country 2 and 1, an intuitive result.

4.1 Comparison of investment levels

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 (5). At the first stage (investment stage), taking the level of investment by its competitor ϕ_{-i}, $-i \neq i$ as given, firm $i = 1, 2$ maximizes, its profit with respect to ϕ_i:

$$\Pi_i^r = p_{i1}^r q_{i1}^r + p_{i2}^r q_{i2}^r - k_i \frac{\phi_i^2}{2} \tag{8}$$

where p_{ij}^r is the function defined in equation (2) evaluated at the quantities defined in (5) and quality vector (v_1^r, v_2^r) is given by $v_i^P = v_i^N = 1 + \phi_1 + \phi_2$ and $v_i^F = 1 + \phi_i$. Solving for the equilibrium (i.e., the intersection of the reaction functions), the total level of innovation available to firm $i = 1, 2$ depends on IPR protection. Details of the computations are given in Appendix 7.2.

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

[15] Appendix **??** shows that for other values of k_1 which are not too big, the investment levels and welfare have the same shape as in the base case and only the value of some thresholds are modified. By contrast, when k_1 becomes very large the innovation levels decrease drastically under all regimes and country 2's incentive to imitate decreases accordingly.

Full IPR protection: In regime F, firms cannot free-ride on each other so that $\phi_i^F = \phi_i$. Their investment in R&D are *strategic substitute* and at the equilibrium $\phi_i^F = \frac{3\frac{k_{-i}}{\alpha}-4}{15\Delta-8}$ for $-i, i = 1, 2$ and $-i \neq i$. Since by convention $k_2 = \Delta k_1 \geq k_1$, the highest quality available to consumers in F 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: In regime N, the level of innovation embodied in good i is $\phi^N = \phi_1^N + \phi_2^N$. Firms' investment in R&D are *strategic complement* and $\phi_i^N = \frac{k_{-i}}{8\Delta-1}\frac{1}{2\alpha}$ for $-i, i = 1, 2$ and $-i \neq i$. We deduce that under assumption 1:

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

Asymmetric IPR protection: In regime P, only country 1 protects IPR. If firm 2 chooses to imitate firm 1, firm 1 also imitates firm 2 so that the innovation embodied in good $i = 1, 2$ is $\phi^P = \phi_1^P + \phi_2^P$. Firms' investment in R&D are *strategic complement* and in equilibrium total innovation is:

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

Comparing (7), (10), and (11) it is easy to check that $\phi^* > \phi^P > \phi^N$ for all $\Delta \geq 1$. The aggregated investment level is higher under partial protection than under no protection at all. This result gives credibility to the idea that stronger IPR protection is conducive to more innovation at the global level. The next result shows the limit 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* $\phi^N \leq \phi^F \leq \phi^P < \phi^*$
- *If* $\Delta > \Delta(\gamma)$ *then* $\phi^N \leq \phi^P < \phi^F < \phi^*$.

Proof. See Appendix 7.2. ■

The result of Proposition 1 is illustrated in Figure 1. The function ϕ^F defined in (9) is increasing and concave in $\Delta \geq 1$. This is because regime F prevents any R&D spillover, so if firm 2 invests less in R&D it has no direct negative effect on the quality ϕ^F produced by firm 1. It has just an indirect positive effect on innovation through better sales for firm 1 as the competitive pressure between the two firms decreases when Δ increases.

By contrast the function ϕ^N defined in (10) is decreasing and convex in $\Delta \geq 1$. This is because the two investment levels are strategic complement under N: If firm 2 invests

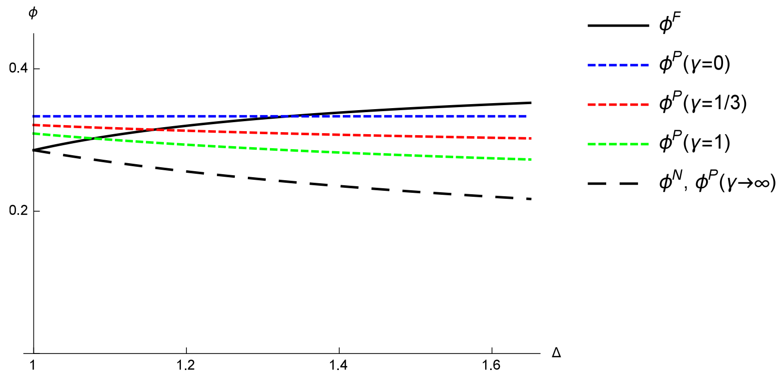

Figure 1: Investment levels

less because it is less efficient, firm 1 invests less too. It is interesting to note that ϕ^F and ϕ^N are equal when $\Delta = 1$, they diverge when Δ increases. The full protection regime is not conducive of more innovation than the no protection regime when the technological gap between the two firms is very small. It just leads to a duplication of R&D costs. This is a case where an universal enforcement of IPR is inefficient.

When firm 2 chooses to free-ride on firm 1 innovation it cannot export the resulting good in country 1. This restriction breaks the symmetry between the two markets. The total investment level ϕ^P in (11) depends both on Δ, the technological gap between the two firms, and on γ, the relative size of demand in country 2 compared to country 1. It is decreasing and convex in γ and in Δ. When the technological gap between the two countries increases the contribution to R&D by firm 2 decreases. Since this investment boosts the investment by firm 1, a larger Δ means a lower level of total innovation. Indeed in the P regime, each firm imitates its rival's innovation and improves upon it through its own R&D activity as innovation is cumulative. More interestingly the total level of innovation is also decreasing and convex in γ, which explains that the threshold value in Proposition 1 $\Delta(\gamma)$ decreases with γ as illustrated Figure 1. Intuitively, when the relative size of the southern market, γ, 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. In the limit (i.e., when $\gamma \to +\infty$) the free-ridding problem is so large that the total level of investment under the partial protection regime P converges towards the low level of investment under the no protection regime N.

4.2 Discussion

Proposition 1 shows that the levels of investments with either no protection or partial protection of IPR are suboptimal compared with the optimal level (7). This 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. Similarly, the total 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. However, this is true 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.[16] More importantly, Proposition 1 shows that total investment in R&D is often higher under regime P than under regime F. In other words, it is not true that stronger protection of IPR always increases global investment. The result depends on the capacity of each country to do R&D. Two cases are particularly policy relevant.

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.[17] When only the firms in the advanced economy (by convention, country 1) invest in R&D, corresponding in our model to $\Delta \to \infty$, the second condition of Proposition 1 holds and market integration without strong IPR yields a low level of investment compared to stronger IPR regimes. By continuity market integration with full patent protection F guarantees the highest level of innovation whenever the two countries have very unequal technological capacity.

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 the investment made by the competition, which in the Nash equilibrium is perceived as exogenous, is a demand booster which stimulates market growth when it can be copied (i.e., in regimes P and

[16] "U.S. Customs estimates 10 million U.S. citizens bring in medications at land borders each year. An additional 2 million packages 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.

[17] 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

N). An increase of investment by firm in country 1 is hence matched by an increase in investment by firm in country 2.[18] 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 under a partial protection system P than under a full protection system F. This equilibrium does not militate for universally strong protection of IPR.

4.3 Robustness

In this section we discuss the robustness of the result of Proposition 1 with regard to our assumptions. Unless specified otherwise, the detail of the computations are omitted to save space. They are available from the authors upon request.

In our base model the production and transportation choices are a black box, and the related costs are normalized to zero in both countries. 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).[19] 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 at the international level).

The assumption of cumulative innovation in case of imitation (regimes P and N), $v_i^N = v_i^P = 1 + \phi_1 + \phi_2$, 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. We have checked the alternative hypothesis that, under imitation, the quality available is the best innovation of the two firms: $v_i^N = v_i^P = 1 + \max\{\phi_1, \phi_2\}$. 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 the F regime is conducive at the global level to more innovation than the P regime, an intuitive result when only the maximum of the two investments matters. This is consistent with results by Lai and Qiu (2003) and Grossman and Lai (2004). In their models innovation is not cumulative, so that an increase in the strength of protection always increases innovation.

The possibility of illegal imports is explored by assuming that if firm 2 copies firm

[18] This strategic complementarity of R&D investment is vivid in the high-tech industry. For instance James Allworth quotes an email from Apple executive Eddy Cue, advocating a change to Apple's lineup of tablet products as a result of him trying out a product that Samsung had released to market. ("Who Cares If Samsung Copied Apple?" James Allworth, Harvard Business Review Blog August 20, 2012).

[19] In open economies firms can choose a variety of arrangements to minimize the sum of production and transportation 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).

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. If $f = 0$ there is no restriction to import of imitated goods in country 1, and we are in regime N. 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 Rey, 2003 and Valletti, 2006).[20]

The case of imperfect imitation is explored by assuming that $v_i^N = v_i^P = 1 + \phi_i + g\phi_{-i}$, 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.[21] This is in line with several empirical studies which find that, when the developing country imitation capacity is lower, the negative impact of weak IPR on imports is less pronounced or disappears (see Fink and Maskus, 2005).

The choice of quantity competition allows us to study vertical differentiation without incurring the Bertrand paradox. If instead we consider price competition, the firm with the higher quality/price ratio captures all the market, so that there is never an equilibrium in which both firms produce and innovate. This is not realistic. Bertrand oligopoly for roughly homogeneous products is hardly ever empirically observed, while Cournot oligopoly has significant empirical relevance (see Brander and Spencer, 2015). To make price competition relevant, it is necessary to add either horizontal differentiation and/or consumer heterogeneity. In an extension we allow for horizontal differentiation between the two firms products. This additional dimension of differentiation increases the complexity of the analysis but it does not change the qualitative results of the paper.[22] Our

[20] 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 Rey, 2003 and Valletti, 2006). This result is partially challenged by Grossman and Edwin (2008) and Valletti and Szymanski (2006).

[21] 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).

[22] Cournot firms invest generally more in R&D than Bertrand firms. The investment gap decreases when horizontal differentiation increases, as differentiation lowers the impact of competition more in the

core result does not depend on the particular form (i.e., price or quantity) competition takes. It depends on the fact that innovation is incremental.

This section has shown that our base result is robust to different variations of the model. Conditionally on the fact that the rich countries are able to protect enough their domestic markets from the importation of IPR infringing products, an asymmetric protection regime can increase the level of innovation at the world level. This result hinges on the fact that innovation is cumulative so that imitation makes firms' contribution strategic complement. It does not hold with drastic innovations, and more generally with non-cumulative (e.g., horizontal) ones. We now decompose the result of Proposition 1 at the industry and country level in order to get implications on the willingness of the different actors to enforce IPR.

5 Choice of 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. There is a sound theoretical justification for the rich country first mover behavior: it always wins to move from N to P, while this is not true for the poor country (see Appendix 7.4.1). 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. We show the following result.

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* $W_2^F < W_2^P$.

Moreover, $\underline{\gamma} < \underline{\gamma}'$, $\overline{\gamma} < \overline{\gamma}'$ *and* $\Delta_2(\gamma) < \Delta_2'(\gamma)$.

case of price than in the case of quantity competition (Lin and Saggi, 2002 and Rosenkranz, 2003). It also decreases when the investment made by one firm benefits the competition (Symeonidis, 2003). Although Symeonidis (2003) considers cost-reducing and not quality-augmenting innovation, this spillover effect is similar to what happens in our model when imitation occurs because both type of innovation increases the net demand (i.e. innovation shifts the price-cost margin upwards).

Proof. See Appendix 7.3. ■

Country 2 prefers strong protection of IPR when its domestic market is relatively small (i.e., when γ is smaller than $\underline{\gamma}$). In this case it is very important for firms in country 2 to have access to the market of country 1. By contrast, when the size of its national market is relatively large, country 2 can afford not to protect IPR (i.e., when γ is larger than $\overline{\gamma}$). For intermediate values of γ ($\underline{\gamma} \leq \gamma \leq \overline{\gamma}$) the result depends on Δ, the efficiency of the R&D system. If the country is relatively efficient at R&D it will prefer to enforce IPR so as to protect its own innovations. If it is relatively inefficient, and therefore innovates little, it will prefer not to enforce IPR.

From an empirical point of view, we expect the strength of the effective protection of IPR to be U-shaped in α_i, the country market intensity (i.e., total 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. In the middle, we expect developing countries with large population, and hence large internal market compared to their export opportunities, to free ride on rich countries' innovations by adopting a lax enforcement of IPR. This free-rider behavior should decrease with the maturity of the country's R&D system.

5.1 Sectorial versus global enforcement of IPR

So far we have focused on a specific sector $s \in S$. For the countries which do not have developed any real R&D capacity (i.e., so that $\Delta \to +\infty$), and which still represent the vast majority of developing countries, the decision that is optimal for one sector is optimal for all of them. More generally, for countries which have homogeneous R&D capacity across sectors, Proposition 2 applies at the country level.[23] Now there are some developing countries where sectors might significantly differ in their R&D performance. There are two cases. First, if international agreements such as TRIPS impose uniform level of enforcement of IPR, countries have to weight the possible welfare gains and losses of stronger IPR enforcement in the different sectors in order to choose the regime that maximizes total welfare. A benevolent social planner in country j maximizes the sum of welfare for all sectors $s \in S$, such as: $r_j^* = arg\max_{r\in\{P,F\}} \int_S \left[a_j(v_{s1}^r q_{s1j}^r + v_{s2}^r q_{s2j}^r) - a_j b_j \frac{(q_{s1j}^r + q_{s2j}^r)^2}{2} - k_{sj}\frac{\phi_{sj}^2}{2}\right] \mathrm{d}s$.

Second, if a country can choose differentiated IPR enforcement for each sector $s \in S$, it will follow the result of Proposition 2 sector-wise. Firms in different sectors will behave

[23]Indeed at the macro level the demand for innovative products depends on macro parameter such as gdp per capita and population size, while investment in R&D and innovative activities in sector $s \in S$ depend on Δ_s. When $\Delta_s = \Delta$, $\forall s \in S$, then the optimal decision is the same in all sectors.

differently, some of them violating IPR of Northern firms while other respecting them to be able to export. Indeed the result in Proposition 2 is the equilibrium if a lax enforcement of IPR leads to global trade sanctions on certain sectors so that firms in these sectors that would respect IPR would not be able to export anyway. If there is no global sanction, 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). When the regime chosen by country 2 is P, firm 2 imitates if and only if $\Pi_2^P \geq \Pi_2^F$. We show in Appendix 7.3.3 that the region in which firm 2 prefers to respect IPR is larger than the region favored by the country 2, 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, to be able to export in country 1. Welfare under P is thus the same as under F in the sense that the country's decision not to enforce IPR does not affect the behavior of the firm. When anticipating this choice, the country is indifferent between enforcing or not IPR in this region (there is now a region of indifference in which the preference of country 2 for regime P becomes weak). In practice it will choose P because this regime better accommodates sectors and firms heterogeneity.[24] The heterogeneity of firms across sectors $s \in S$ militates for a sectorial approach to IPR enforcement, rather than a global one, at the country level.

This result explains why fast-emerging countries, such as India or China, have been reluctant to enforce IPR at the national level as their huge domestic markets developed. For instance prior to 2005, Indian drug producers were allowed (and encouraged) to copy patented medicines of foreign firms to create generic by means of reverse engineering. This measure was introduced in the seventies by the government of India to promote the growth of the domestic market and to produce affordable medicines for the population, which was unable to buy foreign drugs. This deliberate policy of piracy has boosted the Indian pharmaceutical sector, making it able to address local market needs with surpluses that have facilitated exports in direction of other developing countries, especially in Sub-Saharan Africa. The share of pharmaceutical in national exports has hence steadily 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 sector specific policy of IPR infringement did prevent India from exporting its cheap medicines in rich countries but it did not prevent India from exporting textiles and other commodities.

[24]For instance 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 export something, with considerable heterogeneity between domestic firms (only 15.7%-20% are exporting) and foreign-owned ones (60.8%-64.1% are exporters). The exporters respect IPR to be able to sell their production, while the firms which produces only for the Chinese market, are happily stealing technology from the North.

5.2 International conflicts over IPR protection

For country 1, it is not clear that the choice of not protecting IPR in country 2 is necessarily bad. In regime P, when country 2 chooses to steal innovations developed in country 1, this reduces competition in country 1. Moreover 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 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 2 illustrates the results of Propositions 2 and 3 by representing the welfare gains/losses obtained by country $j = 1, 2$ when the regime shifts from P to F (i.e., the sign of $W_j^F - W_j^P$). 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.

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 details). For intermediate values of γ, when country 2 is very inefficient (Δ large), 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 F, while country 1 would prefer to protect its interior market from imports with P.

Concretely, an emerging country incentives to enforce IPR more strictly will rise as it 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. This led Western pharmaceutical companies to lobby for a strict enforcement of IPR at the world level and, eventually, to the TRIPS agreement, which was itself challenged by many countries and later amended on the ground that IPR should not prevent a country from fighting epidemics. However, now that India has developed a full-fledged pharmaceutical industry and built strong R&D capacity, it has changed its

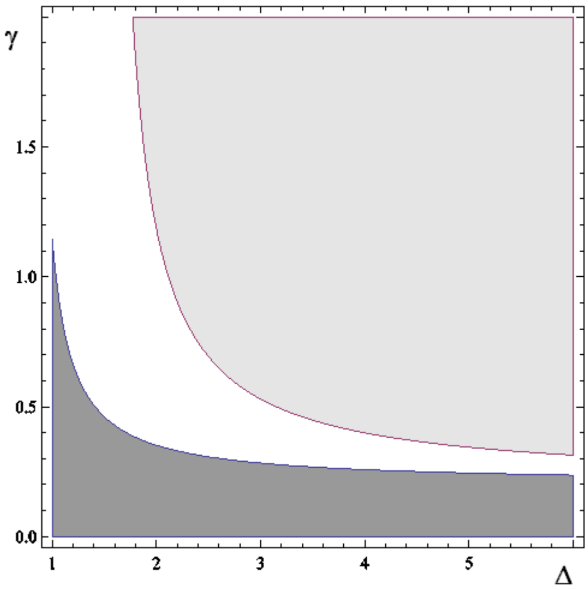

Figure 2: Sign of welfare difference between regimes F and P. In the dark shaded region $W_2^F - W_2^P \geq 0$ and in the light shaded region $W_1^F - W_1^P \geq 0$.

legislation. As a result of the 2005 patent legislation, Indian drug firms can no longer copy medicines with foreign patents.

5.3 IPR and innovation in poor countries

To assess the impact of IPR protection on innovative activities in the South and in the North the result of Proposition 1 is decomposed at the country level. In the base model it is assumed that before investment the two firms can produce the same quality, normalized to 1. However, in real-world situations, the quality of the commodities 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 quality 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 models 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 1 is $v_1^F = 1 + \phi_1^F$.

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

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

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_{d1}^F is always larger than ϕ_1^P. Since most developing countries are either doing no R&D (i.e., $\Delta \to +\infty$) or, when they are doing substantial R&D such as India or China, they have a very large internal market (i.e., γ is large), we predict an increase in innovation activities of the firm in the advanced economy when IPR are better enforced in the developing country. Proposition 4 also implies that the impact of enforcing IPR more strictly tends to have the opposite effect on innovation activities in the developing economy . 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.

The impact of universal IPR on global innovation and on the ability of the South to develop high-tech industries and autonomous research capacity is at the heart of the TRIPS controversy (see Sachs, 2003). The empirical literature on the effects of TRIPS has until recently focused on the pharmaceutical industry. This empirical literature confirms that strict IPR enforcement tend to have an adverse effect on domestic innovation in developing countries, although they can stimulate research in countries with higher levels of economic development (see Chaudhuri et al., 2006, Qian, 2007, Kyle and McGahan, 2012, Williams, 2013). More recently, Auriol et al. (2017) have studied the impact of stronger IPR protection on innovation in a broader set of manufacturing sectors. The paper shows 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 based in developed countries). 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 ones. This empirical finding contradicts again the idea that stronger protection of IPR in developing countries will lead to more patents at the global level.

6 Conclusion

The paper contributes to the understanding of the forces that encourage innovation at the global level, focusing on two issues: first, the incentives that developing countries have to protect IPR; second, the impact of their choices on global innovation. Developing countries face a trade-off between the benefit of free-riding on the advanced economies innovations to serve their internal demand and the cost it yields in term of reduced export opportunities. If the domestic market is large compared to the export market, the benefit outweighs the cost, and conversely if the internal market is relatively small. Since rich countries have an incentive to protect IRP because they are big innovators, the strength of a country's patents protection is a U-shaped function of the relative size of its domestic market with respect to its export opportunities.

By focusing on incremental innovation (quality enhancing) our results complement the trade literature, focused on monopolistic competition with horizontal innovation (a new variety). It yields useful insights on the desirability of enforcing uniformly strong IPR protection. The IPR regime maximizing global innovation depends both on the maturity of the R&D system and on the size of the developing country's internal market. The global level of investment in R&D is higher under a full protection regime of IPR when developing countries are pure free-riders and do not innovate on their own or when innovation is not cumulative (e.g., horizontal innovation). However, with the emergence of new players in the R&D world system, such as China and India, an asymmetric enforcement of IPR, weak in the South and strong in the North, often implies an higher level of investment in R&D. Indeed strict IPR protection reduces the ability of countries to close their technological gap by means of copying and reverse engineering, and therefore to become innovators. With asymmetric protection, investments in R&D of Northern and Southern firms are strategic complement so that investments by firms in the North are matched by investment by firms in the South. Total investment is then larger than with universally strong protection and no technological diffusion.

A limitation of our results is that they are derived from a partial equilibrium analysis. General equilibrium effect could have some impact on our results, for instance through a modification of the wages in the South, if the IPR policy could affect the capability of firms to produce innovative goods and the size of Southern firms. This general equilibrium issues are discussed in Branstetter and Saggi (2011), who note however that the effect on wages might not be large in practice, as IPR reforms do not affect all goods produced in the economy but only a handful of innovative sectors. When the innovative sector is small compared to the rest of the economy, which is the case in most countries, especially developing ones, partial equilibrium analysis might not be very restrictive. Anyhow, we believe that an extension to a general equilibrium framework could be an interesting development for further research.

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7 Appendix:

7.1 The demand function

Substituting $w_j = R_j - \int_S (p_{s1j}x_{s1j} + p_{s2j}x_{s2j})\mathrm{d}s$ in (1) and optimizing with respect to x_{sij} yields: $\frac{\partial U_j}{\partial x_{sij}} = -p_{sij} + a_j v_{sij} - a_j(x_{s1j} + x_{s2j})$ $(i = 1, 2,\ j = 1, 2,\ s \in S)$. If $a_j v_{sij} - p_{sij} > a_j v_{sj\,-i} - p_{sj\,-i}$ then $x_{sj\,-i} = 0$ and $x_{sij} = v_{sij} - p_{sij}/a_j$. If $a_j v_{sij} - p_{sij} = a_j v_{sj\,-i} - p_{sj\,-i}$ the representative consumer demand is $x_{s1j} + x_{s2j} = v_{sij} - p_{sij}/a_j$. Let N_j be the size of the population in country $j = 1, 2$, the total demand in country $j = 1, 2$ in sector $s \in S$ is $q_{s1j} + q_{s2j} = N_j(v_{sij} - p_{sij}/a_j)$. Letting $b_j \equiv \frac{1}{N_j}$, the aggregated inverse demand for good $i = 1, 2$ in sector $k \in K$ in country $j = 1, 2$ is $p_{sij} = a_j(v_{sij} - b_j(q_{s1j} + q_{s2j}))$. It increases with the gdp per capita (i.e., it increases with a_j)[25] and with the population size (i.e., it decreases with $b_j = 1/N_j$) in country $j = 1, 2$.

7.2 Proof of Proposition 1

We derive the result under the general case where exporting to a foreign country implies a unit transportation cost equal to $t \geq 0$. The results of the base model are simply obtained by fixing $t = 0$. The total profit of firm i is written as:

$$\Pi_i^D = p_{i1}q_{i1} + p_{i2}q_{i2} - tq_{ij} - k_i \frac{\phi_i^2}{2} \tag{12}$$

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

$$q_{ij}^D = \frac{2v_i^r - v_{-i}^r}{3b_j} + \frac{2t}{3a_i b_j}\ , \qquad i, -i, j \in \{1, 2\}, i \neq -i \tag{13}$$

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

- *The socially optimal level of investment*: Optimizing $W = W_1^r + W_2^r$ with the profit function being replaced by (12) and the quantity formula by (13), the socially optimal level of innovation in country $j = 1, 2$ becomes:

  $$\phi_j^* = \frac{\alpha - t\frac{b_1+b_2}{2b_1b_2}}{\frac{9}{8}\frac{k_1k_2}{k_1+k_2} - \alpha}\ \frac{k_j}{k_1 + k_2} \tag{14}$$

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

  $$\phi^* = \frac{4(\Delta + 1)}{5\Delta - 4} - \frac{t}{\alpha b_1 b_2}\frac{2(\Delta + 1)}{5\Delta - 4} \tag{15}$$

[25] In our stylized model w_j is the consumption of the numeraire and an increase in a shifts the demand up for the vertically differentiated varieties. Alternatively $1/a$ can be interpreted as the marginal utility of income, which typically decreases with per capita income.

For $t = 0$, this corresponds to equation (7). For $t > 0$, the symmetry between the two countries is broken: a decrease in transportation costs always increases investment, and this effect is larger when the population of the two countries increases. The higher the population size $1/b_j$ $(j = 1, 2)$, the higher the investment.

- *Full IPR protection (F regime)*: Substituting the quantities (13) in the profit function, firm i maximizes (12) with respect to ϕ_i, for a given level of ϕ_{-i}, $i \neq -i$. Profit maximization gives the reaction function:

$$\phi_i(\phi_{-i}) = \frac{\alpha(1 - \phi_{-i}) - \frac{2b_i - b_{-i}}{b_i b_{-i}} t}{2.25k_i - 2\alpha} \tag{16}$$

The slope of the reaction function is negative: $\frac{\partial \phi_i(\phi_{-i})}{\partial \phi_{-i}} < 0$. Quality levels (and thus investment levels) are *strategic substitutes*. Solving the system of first-order conditions, we obtain:

$$\phi_i^F = \frac{1}{2} \frac{\alpha(1 - \frac{\alpha}{3k_{-i}})\frac{k_{-i}}{k_1+k_2} - \frac{t}{k_1+k_2}(k_{-i}(\frac{2}{b_{-i}} - \frac{1}{b_{-i}}) - \frac{4\alpha}{3b_{-i}})}{\frac{9}{8}\frac{k_1 k_2}{k_1+k_2} - \alpha(1 - \frac{\alpha}{3\frac{k_1+k_2}{2}})} \tag{17}$$

The level of quality chosen by firm i depends negatively on k_i and positively on k_{-i}. Moreover ϕ_i^F decreases with t if and only if $\frac{b_{-i}}{b_i} \leq 2 - \frac{4}{3}\frac{\alpha}{k_{-i}}$. This inequality is easier to satisfy when k_{-i} increases. Let $\Delta = \frac{k_2}{k_1}$. Under assumption 1, the two equilibrium investment levels can be written as:

$$\phi_1^F = \frac{6\Delta - 4}{15\Delta - 8} - \frac{t}{\alpha}\frac{6(\frac{2}{b_2} - \frac{1}{b_1})\Delta - \frac{4}{b_2}}{15\Delta - 8} \tag{18}$$

$$\phi_2^F = \frac{5}{15\Delta - 8} - \frac{t}{\alpha}\frac{(\frac{4}{3b_1} - \frac{1}{b_2})}{15\Delta - 8} \tag{19}$$

Setting $t = 0$ we find that the highest quality available to consumers is $\phi^F = \max\{\phi_1^F, \phi_2^F\} = \phi_1^F$, which yields equation (9). When $t > 0$, a decrease of the transportation cost increases the level of investment of country 1 (resp. 2) if and only if country 2 (resp. 1) is relatively large in terms of population.[26]

- *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

[26] Interestingly, the same effect does not occur when per capita revenue increases. Starting from a symmetric situation ($a_1 = a_2$), 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.

given by the Cournot levels in (5). At the first stage, profit maximization gives the reaction functions:

$$\phi_i(\phi_{-i}) = \frac{\alpha(1+\phi_{-i}) - \frac{2b_i - b_{-i}}{b_i b_{-i}} t}{4.5k_i - \alpha} \tag{20}$$

In this case the slope of the reaction function is positive: $\frac{\partial \phi_i(\phi_{-i})}{\partial \phi_{-i}} > 0$. Quality levels (and thus investment) are *strategic complements*. 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:

$$\phi_i^N = \frac{\alpha \frac{k_{-i}}{k_1+k_2} - \frac{t}{k_1+k_2}\left(k_{-i}\left(\frac{2}{b_{-i}} - \frac{1}{b_i}\right) - \frac{2}{3}\alpha\left(\frac{1}{b_{-i}} - \frac{1}{b_i}\right)\right)}{4.5\frac{k_1 k_2}{k_1+k_2} - \alpha} \tag{21}$$

As before, investment in country i increases with k_{-i} and decreases with k_i. Moreover, ϕ_i^N decreases with t if and only if $\frac{b_{-i}}{b_i} \leq \frac{2(3k_{-i}-\alpha)}{3k_{-i}-2\alpha}$. This inequality is easier to satisfy when k_{-i} decreases. Moreover, a decrease of the transportation cost increases the level of investment of country i if and only if country $-i$'s population is relatively large. Under assumption 1, the total quality under N can be written as:

$$\phi^N = \phi_1^N + \phi_2^N = \frac{\Delta+1}{8\Delta-1} - \frac{t}{\alpha}\frac{\left(\left(\frac{1}{b_2} - \frac{2}{b_1}\right) + \left(\frac{1}{b_1} - \frac{2}{b_2}\right)\Delta\right)}{8\Delta-1}. \tag{22}$$

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.

- *IPR protection only in one country (P regime)*: When only one country protects IPR, the quality of good i after investment is given by $\phi^P = \phi_1^P + \phi_2^P$. At the first stage, profit maximization gives the reaction functions:

$$\phi_1(\phi_2) = \frac{(1+\phi_2)(2.25\alpha_1 + \alpha_2) - \frac{2t}{b_2}}{4.5k_1 - (2.25\alpha_1 + \alpha_2)} \tag{23}$$

$$\phi_2(\phi_1) = \frac{(1+\phi_1)\alpha_2 + \frac{t}{b_2}}{4.5k_2 - \alpha_2} \tag{24}$$

In the case of partial protection of IPR, investments are *strategic complements.* Solving for the equilibrium we have:

$$\phi_1^P = \frac{(2.25\alpha_1+\alpha_2)k_2 - \frac{t}{b_2}(2k_2 - \frac{1}{2}\alpha_1 - \frac{2}{3}\alpha_2)}{4.5k_1k_2 - (2.25\alpha_1+\alpha_2)k_2 - \alpha_2 k_1} \tag{25}$$

$$\phi_2^P = \frac{\alpha_2 k_1 + \frac{t}{b_2}(k_1 - \frac{1}{2}\alpha_1 - \frac{2}{3}\alpha_2)}{4.5k_1k_2 - (2.25\alpha_1+\alpha_2)k_2 - \alpha_2 k_1} \tag{26}$$

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:

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

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 (15), (22), and (27) it is easy to check that $\phi^* > \phi^P \geq \phi^N$. 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:

$$\frac{\partial(\phi^F - \phi^P)}{\partial\Delta} = 12\left(\frac{12\gamma(\gamma+1)}{(27\Delta+4\gamma(8\Delta-1))^2} + \frac{1}{(15\Delta-8)^2}\right) \geq 0 \tag{28}$$

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., $\Delta \to \infty$).

$$(\phi^F - \phi^P)|_{\Delta\to 1} = -\frac{9}{7(28\gamma+27)} < 0$$

$$(\phi^F - \phi^P)|_{\Delta\to\infty} = \frac{44\gamma+9}{160\gamma+135} > 0$$

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. QED

Now consider $t > 0$. Using equations (15),(18), (19), (22) and (27) it is easy to see that the innovation levels keep the same shape as for $t = 0$. Using (18) and (27) one can check that 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 difference $\phi^F - \phi^P$ is increasing in 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

7.3.1 Social welfare functions with different IPR regimes

The net consumer surplus in country $j = 1, 2$ is:

$$S_j^r = a_j(v_1 q_{1j}^r + v_2 q_{2j}^r) - a_j b_j \frac{(q_{1j}^r + q_{2j}^r)^2}{2} - p_{1j}^r q_{1j}^r - p_{2j}^r q_{2j}^r \tag{29}$$

Adding the national consumer's surplus to the national firm profit, we obtain the utilitarian welfare in country $j = 1, 2$. Under full protection of IPR (F), it is:

$$W_j^F = \frac{1}{18}\left[3\alpha_j\Big(2(1+\phi_j^F)^2 + (\phi_j^F - \phi_{-j}^F)^2\Big) + 2\alpha_{-j}(1 + 2\phi_j^F - \phi_{-j}^F)^2\right] - k_j \frac{(\phi_j^F)^2}{2} \tag{30}$$

Similarly under no protection of IPR (N), welfare in country $j = 1, 2$ is:

$$W_j^N = \frac{1}{9}(3\alpha_j + \alpha_{-j})(1 + \phi_1^N + \phi_2^N)^2 - k_j \frac{(\phi_j^N)^2}{2} \tag{31}$$

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

$$W_2^P = \frac{1}{3}\alpha_2(1 + \phi_1^P + \phi_2^P)^2 - k_2 \frac{(\phi_2^P)^2}{2} \tag{32}$$

In country 1 it is:

$$W_1^P = \frac{1}{72}(27\alpha_1 + 8\alpha_2)(1 + \phi_1^P + \phi_2^P)^2 - k_1 \frac{(\phi_1^P)^2}{2} \tag{33}$$

7.3.2 Optimal choice of IPR regime for country 2

We derive the optimal policy regarding IPR enforcement from the country 2 point of view. Substituting the investment equilibrium value, (18) and (19) where $t = 0$, in (30) welfare in 2 under full protection of IPR can be written as:

$$W_2^F = \frac{\alpha(\gamma(\Delta(81\Delta - 76) + 18) + \Delta(9\Delta - 4))}{(\gamma + 1)(8 - 15\Delta)^2} \tag{34}$$

Setting $t = 0$ in (25) and (26), 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 (32) 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 (34) and (35), we can write the welfare difference $W_2^F - W_2^P$ as:

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

It is straightforward to check that:

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

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 the result of Proposition 2.

7.3.3 Firm 2 choice between F and P

We compare profits under the regime P and F. The following result holds.

Lemma 1 *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:

$$\Pi_2^F = \frac{\alpha\Delta(9\Delta-4)}{(15\Delta-8)^2} \tag{38}$$

$$\Pi_2^P = \frac{\alpha 16\gamma\Delta(9(1+\gamma)\Delta-\gamma)}{(27\Delta+4\gamma(8\Delta-1))^2} \tag{39}$$

Comparing equation (38) with (39), it is easy to verify that:

$$\begin{aligned}
\frac{\partial(\Pi_2^F-\Pi_2^P)}{\partial\Delta} &= \frac{4}{5}\alpha\left(-\frac{5(21\Delta-8)}{(15\Delta-8)^3}+\frac{20\gamma^2(5(8\gamma+9)\Delta-4\gamma)}{(27\Delta+4\gamma(8\Delta-1))^3}\right)\leq 0\\
(\Pi_2^F-\Pi_2^P)|_{\Delta\to 1} &= -\alpha\frac{3\,(784\gamma^2-168\gamma-1215)}{49(28\gamma+27)^2}\\
(\Pi_2^F-\Pi_2^P)|_{\Delta\to\infty} &= -\alpha\frac{2576\gamma^2+1872\gamma-729}{25(32\gamma+27)^2}
\end{aligned}$$

Term $\Pi_2^F-\Pi_2^P$ 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 $\Delta\to\infty$, the difference is positive if and only if $\gamma\geq\overline{\gamma}'\simeq 1.36$. We deduce the result. ■

Comparing the different thresholds, it is easy to check that $\underline{\gamma}$ in Proposition 2 is lower than $\underline{\gamma}'$ in Lemma 1 and $\overline{\gamma}$ is lower than $\overline{\gamma}'$. Moreover, $\Delta_2(\gamma)$ is smaller than $\Delta_2'(\gamma)$. This implies that the region in which country 2 prefers IPR to be respected is smaller than the one in which firm 2 prefers not to imitate. The region defined by Proposition 2 is dark-shaded in Figure 2. The region defined by Lemma 1 has the same shape, but it is larger (i.e., it is shifted to the north-est).

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 1 is defined as in (30), and under no protection (N) it is defined as in (31), while under partial protection (P) it is defined in (33). Substituting the investment equilibrium value, under assumption 1, welfare under full protection of IPR (F) can be rewritten as:

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

Under partial protection (P) it is:

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

Finally, under no protection (N) it is:

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

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

$$\begin{aligned}
(W_1^F-W_1^P)|_{\Delta\to 1} &= -\frac{6\alpha(\gamma(7\gamma(56\gamma+191)+1461)+513)}{49(\gamma+1)(28\gamma+27)^2}<0\\
(W_1^F-W_1^P)|_{\Delta\to\infty} &= \frac{\alpha(2\gamma(\gamma(960\gamma+2401)+1017)-648)}{25(\gamma+1)(32\gamma+27)^2}
\end{aligned}$$

$$\frac{\partial(W_1^F - W_1^P)}{\partial\Delta} = \frac{4\alpha}{5(\gamma+1)}\left(5\gamma\left(\frac{2(\gamma+1)(2\gamma(64\gamma+279)+405)\Delta}{(4\gamma(8\Delta-1)+27\Delta)^3} + \frac{15(3\Delta-2)}{(15\Delta-8)^3}\right) + \frac{15(9\Delta-7)}{(15\Delta-8)^3}\right) \geq 0 \quad (43)$$

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

7.4.1 Country 1 choice between P and N

We start from a situation where country 1 always enforces IPR because advanced economies have been the first to adopt strong IPR legislations. This first mover behavior can easily be generated in our model. Starting from a situation where initially IPR are not protected (i.e., regime N), country 1 chooses to move to regime P to protect them domestically. To see this, we use equations (40) and (42) to compute the welfare difference:

$$W_1^P - W_1^N = \alpha\Delta^2\left(\frac{405 + 2\gamma(279 + 64\gamma)}{(\Delta(27 + 32\gamma) - 4\gamma)^2} - \frac{2(13 + 4\gamma)}{(8\Delta - 1)^2(1 + \gamma)}\right) \quad (44)$$

This welfare difference $W_1^P - W_1^N$ is always positive for $\Delta \geq 1$ and $\gamma \geq 0$, 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 advanced economies have been the first to enforce IPR. By contrast we can show (computations available from the authors upon request) that this result does not hold for country 2. Starting from N it is not necessarily welfare improving for country 2 to start protecting its IPR while country 1 does not.[27]

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 $v_1^F = 1 + \phi_1^F$

[27] To prove this, we compare regime N with a modification of regime P in which the roles of country 1 and 2 are reversed. In this new regime when imitation takes place the most efficient, firm 1, is not allowed to sell in country 2.

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:

$$\phi_{2d}^F = \max\left\{\frac{2-8d}{15\Delta - 8}, 0\right\} \quad (45)$$

and firm 1's investment is:

$$\phi_{1d}^F = \tfrac{6(1+d)\Delta - 4}{15\Delta - 8} \quad if \;\; \phi_{2d}^F > 0; \quad (46)$$

$$\phi_{1d}^F = \tfrac{2}{5}(1+d) \quad otherwise. \quad (47)$$

As intuition suggests, ϕ_{1d}^F increases and ϕ_{2d}^F decreases in d. Comparing equation (45) with (26) 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 (46) with (25) (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 Global welfare analysis

We conclude the theoretical analysis by a brief presentation of the optimal policy from a collective utilitarian point of view. 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 3 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 ($\Delta \to \infty$).

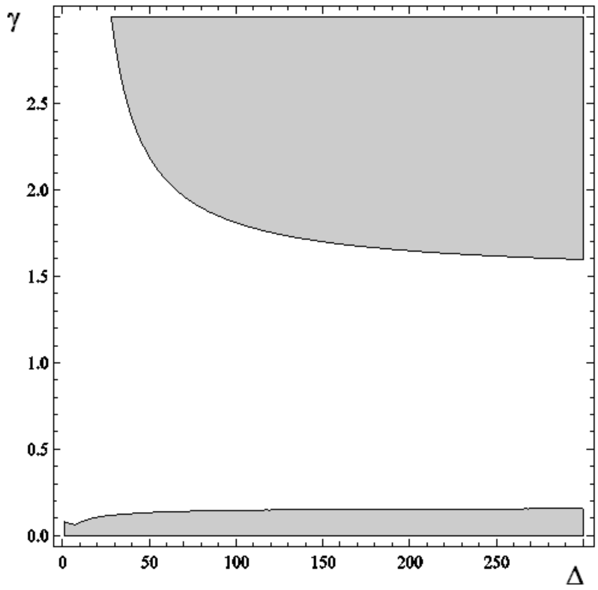

Figure 3: Total welfare difference: $(W_1^F + W_2^F) - (W_1^P + W_2^P)$. In the colored region $(W_1^F + W_2^F) - (W_1^P + W_2^P) > 0$.

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.