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 their export opportunities to advanced economies but slows down technological transfers and their 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 domestic market compared to the foreign one: 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. Finally rich countries enforce IPR to protect their innovations.

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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 worldwide 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. More studies are needed to illuminate the pros and cons of universal enforcement of IPR.

We study the impact of different IPR regimes (no protection; partial protection where

[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 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).

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

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 commodity. 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 for instance the report of the Congressional Budget Office, 2006 for drugs and Acemoglu et al., 2016 for a network analysis of the cumulative process of innovation in a wide variety of sectors). 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.[4] In other cases sanctions were implemented.[5] 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).[6] For instance in 1989, the US put China on the Priority Watch List, which is the first stage of the Section 301 mechanism. In the middle of the 1990s, the two countries signed a special agreement when the United States announced their intention to apply a 3 billion US dollars in punitive tariffs on Chinese importations (Harris, 2008, p. 107). Nonetheless, IPR violations persisted and the United States changed its strategy by pushing China to sign the TRIPS agreement in the context of its WTO accession. Problems of IPR infringement are since handled in

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

[5]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).

[6]One of the first disputes in 1985 has resulted in the signature of a bilateral agreement to improve product patent protection and enforcement procedures in Korea (see "Korea Intellectual Property Rights" Case 301-52). Similarly in 1988, Brazil's weak patent protection for pharmaceutical resulted in a 100% punitive tariff imposed by the US on Brazilian pharmaceutical, paper products and consumer electronics ('Brazil Pharmaceuticals" Case 301-61). In the early 1990s, Brazil changed its legislation to see the sanctions lifted (Sell, 1995). In 2000, other disputes between the US and Brazil were handled in the context of the WTO dispute settlement process and were resolved through negotiation ("Brazil - Measures Affecting Patent Protection", WTO Dispute DS199).

the framework of the WTO dispute settlement process.[7]

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 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: it can copy its competitor's innovations, if any, even while IPR act as a barrier to its competitor entering into its market.[8] 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: strict IPR enforcement tend to have an

[7] "China - Measures Affecting the Protection and Enforcement of Intellectual Property Rights", WTO Dispute DS362.

[8] An imitator can hardly file a patent application on its incremental improvements of the copied technology in the foreign country, because this innovation is obtained by infringing other patents. Then, in our base model the incremental improvements developed by firms infringing Northern patents is not protected by IPR. In the robustness section this assumption is relaxed.

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).

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 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: advanced economies and poor countries of small size are willing to enforce IPR, the former to protect its innovations, the latter to access foreign markets, while big emerging countries prefer to free-ride on advanced economies technologies to serve their large internal demand. Emerging economies are willing to enforce IPR when they themselves start to invest heavily in R&D and become major innovators. 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. This literature focuses on IPR protection in a domestic context.

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 literature is the impact of IPR infringement on trade and on horizontal innovation (i.e., innovation is non-incremental and consists in 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. 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).

One problem with the trade literature is that it focuses on monopolistic competition and therefore on non-cumulative innovation, typically a new product variety. Moreover it assumes that the North is both the main innovator and the main market. These assumptions imply 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. In practice the vast majority of innovations are incremental[9] and some developing countries, such as China or India, are both very large and investing heavily in R&D.[10]

In our model countries differ not only in per capita income, but also in population size. Because of the size of its population, the developing economy can be larger than the developed one, although poorer in per capita term and generally endowed with less efficient R&D technology. We assume that both countries can potentially innovate. We focus on vertical innovation (see Motta, 1993, Sutton, 1991, 1997), which allows us to study incremental innovation in the form of quality improvement. Consumer utility is quadratic. Di Comite et al. (2014) show that quadratic utilities allows to give a meaningful

[9]As explained in the introduction empirically most new products are incremental improvements on existing ones. Isaac Newton summarized this process of cumulative innovation in 1676 "If I have seen further, it is by standing on the shoulders of giants."

[10]China is today the second investor in R&D in the world (see WIPO Publication No. 941E/2011 ISBN 978-92-805-2152-8 at www.wipo.int).

representation of vertical differentiation (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.

In our base case model, we have a continuum of innovative sectors. In each sector there are two firms (one in the North and one in the South), which in a first stage can invest in R&D. In a second stage, they compete in quantities à la Cournot. The choice of quantity competition allows us to study vertical differentiation without incurring the Bertrand paradox.[11] In fact Bertrand oligopoly for highly substitutable products is hardly ever empirically observed, contrary to Cournot oligopoly (see Brander and Spencer, 2015).

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. The latter regime is not necessarily conducive of more innovation at the world level because, by preventing the diffusion of knowledge, it impedes the South from becoming an innovator. Symmetrically, in the limit case where innovation is not cumulative, as it is generally assumed in the trade literature, the free-rider effect dominates and we find that stronger IPR increases the total level of innovation. Our result that universally strong IPR regime is not necessarily conducive of more innovation at the world level 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.[12]

[11]To make the price competition model relevant, it is necessary to either add horizontal differentiation and/or consumer heterogeneity. This makes the analysis more complex without the benefit of enriching our understanding of the role of IPR on incremental innovation: the trade-off studied below is unchanged. Hence comparing Cournot and Bertrand, Lin and Saggi (2002) and Rosenkranz (2003) show that Cournot firms generally invest more than Bertrand firms, but the gap is reduced if there is horizontal differentiation as it lowers the impact of competition more in Bertrand than in Cournot. Similarly Symeonidis (2003), in a context with both vertical and horizontal differentiation, shows that under Bertrand competition firms generally invest less than under Cournot, but the gap is reduced when there are innovation spillovers (i.e. when the investment made by one firms also benefits the competitors). This spillover effect is similar to what happens in our model when imitation occurs. Symeonidis (2003) considers cost-reducing and not quality-augmenting innovation. Yet the intuitions are similar because both types of innovation have the effect of increasing the net demand (i.e. innovation shifts the price-cost margin upwards).

[12]In our case strong IPR forbids firms to exploit the innovations of the competitors through imitation, but innovation can still be developed without infringing existing patents by duplicating fixed R&D costs.

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 the R&D investment levels 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 focus on research intensive industries where firms have market power due to their innovative activities. We consider a two-countries economy and focus on a set K of innovative sectors. In each innovative sector, a national and a foreign firm produce a vertically differentiated good. The utility of a representative consumer consuming two goods of qualities v_{1k} and v_{2k} from sectors $k \in K$ is quasi-linear. It is given by:

$$U = w + \int_K a \left(v_{k1}x_{k1} + v_{k2}x_{k2} - \frac{(x_{k1} + x_{k2})^2}{2} \right) \mathrm{d}k \tag{1}$$

where w is the numeraire, x_{ki} is the quantity consumed of good $i = 1, 2$ in sector $k \in K$ and a is a parameter reflecting the relative 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 is increasing with the representative consumer wealth.[13] The representative consumer has income R and maximizes utility U under the budget constraint:

$$w + \int_K (p_{k1}x_{k1} + p_{k2}x_{k2})\mathrm{d}k = R.$$

Substituting $w = R - \int_K (p_{k1}x_{k1} + p_{k2}x_{k2})\mathrm{d}k$ in (1) and optimizing with respect to x_{ki} yields: $\frac{\partial U}{\partial x_{ki}} = -p_{ki} + av_{ki} - a(x_{k1} + x_{k2})$ $(i = 1, 2,\ k \in K)$. If $av_{ki} - p_{ki} > av_{kj} - p_{kj}$ then $x_{kj} = 0$ and $x_{kj} = v_{ki} - p_{ki}/a$. If $av_{ki} - p_{ki} = av_{kj} - p_{kj}$ the representative consumer demand is $x_{k1} + x_{k2} = v_{ki} - p_{ki}/a$. Let N be the size of the population, the total demand in sector k is $q_{k1} + q_{k2} = N(v_{ki} - p_{ki}/a)$. Letting $b \equiv \frac{1}{N}$, the aggregated inverse demand

In this case products produced in the South are of poorer quality than products in the North.

[13]The poor of the world allocate a larger share of their income to buy food, energy, housing and transportation services than the rich. The rich consume more high-tech products and services, such as pharmaceutical, healthcare, entertainment services, sophisticated electronics. For instance food consumption absorbs close to 50% of household spending in Cameroon, but less than 10% in the US. Similarly, the share of imports of primary products and resource-based manufactures are higher than world average for low-income and lower-middle-income countries. They exhibit particularly low levels of imports of high technology products (see Lall, 2000). In our stylized model w 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 good $i = 1, 2$ in sector $k \in K$ is $p_{ki} = a(v_{ki} - b(q_{k1} + q_{k2}))$. It increases with the gdp per capita (i.e., it increases with a) and with the population size (i.e., it decreases with $b = 1/N$).

We next turn to the two countries setting. In country j the price of good i in sector k becomes p_{kij}, and the total quantity of commodities demanded in sector k in country j is, $q_{k1j} + q_{k2j}$. This 3 indices notation is heavy. For the sake of simplifying it, we drop the index $k \in K$. In the following all our results are derived *at the sector level*. This is done without loss of generality as the quasi-linear utility function is additively separable in each of the $k \in K$ components.

If we drop the index $k \in K$, with two countries, the price of good i in country j becomes p_{ij}, and the total quantity in country j, $q_{1j} + q_{2j}$. Inverse demand for good i in country j is written as:

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

where q_{ij} is the quantity of good i sold in country j, v_i represents the quality of good i, and $a_j > 0$ and $b_j > 0$ are exogenous parameters reflecting per capita wealth and population size respectively. A larger population size in country j implies a lower b_j, while a larger gdp per capita implies a larger a_j.

Our demand in each sector corresponds to a quality augmented version of the linear demand model for differentiated goods proposed by Singh and Vives (1984). Quality augmented versions of the Singh and Vives (1984) model were initially introduced by Sutton (1991, 1997) and later used by Symeonidis (2003) to study quality-enhancing innovation in a model with horizontally differentiated goods and R&D spillovers.[14]

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 et al., 2006). In our model competitors sell two vertically differentiated qualities. Income differences across countries influence demands for the different qualities.

Without loss of generality we assume that the developing economy is country 2 and

[14]Symeonidis (2003) aims to compare R&D investment in Bertrand and Cournot competition. In this end the model includes horizontal differentiation and focuses on symmetric investment equilibria (i.e. firms have identical technologies and equal equilibrium levels of innovation). In contrast our model analyzes the impact of heterogeneous technologies on innovation. In this end it focuses on vertical differentiation with Cournot competition.

the advanced economy is country 1 (i.e., the per capita GDP is higher in 1 than in 2): $a_1 > a_2$. By contrast there is no natural order for b_1 and b_2: the population size might be smaller in 1 or in 2. Then the parameter $\alpha_i = a_i/b_i$ 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

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

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 normalized to 1, innovation increases the quality of the commodity by ϕ_i. 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 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 $v_i = 1 + \phi_i$.[15] We assume that firm 1, based in country 1, has the most efficient R&D process (i.e., country 1 is the advanced economy).

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

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. In the second stage, they compete in quantities (Cournot game). To keep the exposition simple, we as-

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

sume that, once an innovation is developed, production costs are normalized to zero.[16] 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. When violating the patent rights of firm 1, firm 2 will not be able to sell its product in country 1. Moreover, firm 1 can reproduce the incremental technological improvement developed by firm 2, if any, so that $v_i^P = v_i^N = 1 + \phi_i + \phi_j$. This is because firm 1 produces innovation infringing IPR and cannot claim protection even in Country 1.

If both countries enforce IPR (regime F), imitation is not allowed and each firm privately exploits the benefits of its R&D activity. If both countries do not enforce IPR (regime N), imitation occurs in both countries (i.e., both firms can imitate). In the case of imitation, each firm imitates its rival's innovation and improves upon it through its own R&D activity (i.e., innovation is cumulative). The same happens if only country 1 protects IPR and firm 2 decides to free-ride and imitate innovation (regime P).

Note that when describing regime P we focus on what happens if firm 2, based in a country which does not protect IPR, effectively decides to imitate firm 1 and thus faces reduced export opportunities. This would always be the case if low IPR protection by country 2 triggers trade sanctions, which reduce the export opportunity of all firms in country 2. If the country is subject to trade sanction and, independently of their individual behavior, firms cannot export then they will copy the foreign technology. However, we can also consider the case in which there is no sanction, just the ban of importation of products from country 2 infringing on IPR of country 1. 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. It is indeed possible that a firm decides to respect

[16] 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.

IPR even if this is not desirable from the point of view of the Southern country's total welfare, because the firm does not take into account the negative effect of IPR protection on domestic consumers. The firm focuses on its profit only. It will respect IPR to be able to export if it is in its best interest. When firm 2 decides to respect patents, although the home country does not impose it, it will also patent its own innovation in country 1, to avoid imitation from firm 1. In the later case, there is no imitation under P and everything is as in regime F.[17] For this reason, we use the superscript P as a notation to identifies variables (quantity, profits, welfare) in the case in which country 2 chooses regime P and imitation by firm 2 takes place.

Since our focus is on the innovative activity, we do not detail how firms organize the physical location of production and shipments. 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 the technology to a foreign firm through a production-licensing agreement. In each case, the innovator can design the contractual relationship with the manufacturer in order to extract as much profit as possible. In our base model, the choice of production allocation is a black-box and the related costs are normalized to zero.[18]

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 firm 2 if the latter decide to be an imitator. In this case firm 1 is 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 (2) 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

[17] We do not allow here firms to produce two version of the goods, one infringing the competitor's patent, and the other respecting it.

[18] Appendix 7.1 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).

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:

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

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

$$\Pi_i^r = p_{i1}^r q_{i1}^r + p_{i2}^r q_{i2}^r - k_i \frac{\phi_i^2}{2} \tag{6}$$

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 $v_i^P = v_i^N = 1 + \phi_i + \phi_j$ and $v_i^F = 1 + \phi_i$ $i, j = 1, 2$.

4 Investment in R&D

As a benchmark case we first compute the optimal investment level from a global social point of view when the production levels are defined by (5). 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 (6) and

$$S_j^r = a_j(v_1 q_{1j}^r + v_2 q_{2j}^r) - a_j b_j \frac{(q_{1j}^r + q_{2j}^r)^2}{2} - p_{1j}^r q_{1j}^r - p_{2j}^r q_{2j}^r \tag{7}$$

with q_{ij}^r defined equation (5). The optimal investments ϕ_1 and ϕ_2 are the levels chosen by a centralized authority maximizing total welfare:

$$W = W_1^r + W_2^r. \tag{8}$$

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 (6) and (7), 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 $k_1 > \frac{8}{9}\frac{1+\Delta}{\Delta}\alpha$.[19] 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 $k_1 = 2\alpha$

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

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.[20] 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:

$$\phi^* = \frac{4(\Delta + 1)}{5\Delta - 4}. \tag{9}$$

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 (5). At the first stage (investment stage), firm i maximizes the profit (6) with respect to ϕ_i, for a given level of ϕ_j, $i \neq j$. The level of innovation available to firm i depends on IPR protection. Details of the computations of the different cases is given in Appendix 7.1.

Full IPR protection (F regime): In the case of universal IPR protection, firms cannot free-ride on each other's innovation. Their investment in R&D are strategic substitute. 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:

$$\phi^F = \frac{6\Delta - 4}{15\Delta - 8}. \tag{10}$$

No IPR protection (N regime): When IPR are not protected, firms imitate the innovations of their competitors. Their investment in R&D are strategic complement. 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:

$$\phi^N = \frac{\Delta + 1}{8\Delta - 1}. \tag{11}$$

Asymmetric IPR protection (P regime): When only country 1 protects IPR, if firm 2 chooses to imitate, firm 1 can also imitate the innovation of firm 2 so that the quality of

[20] Appendix 8.1 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.

good $i = 1, 2$ after investment is given by $\phi^P = \phi_1^P + \phi_2^P$. Their investment in R&D are strategic complement. In this case, both firms can sell in the market of country 2, but the goods produced by firm 1 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 when imitation takes place is $\phi^P = \phi_1^P + \phi_2^P$ is :

$$\phi^P = \frac{9\Delta + 4\gamma(1+\Delta)}{27\Delta + 4\gamma(8\Delta - 1)}. \tag{12}$$

When firm 2 chooses to free-ride on innovation by firm 1 it cannot export the resulting good 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 (9), (11), and (12) 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 (9). 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.[21]

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.

[21] "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).

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 7.1. ■

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.

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.[22] 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, 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

[22]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

system F.[23] This equilibrium does not militate for universally strong protection of IPR.

Third, the threshold value $\Delta(\gamma)$ decreases with the ratio γ. Intuitively, 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.

4.2 Discussion and robustness

In this section we discuss the robustness of the result of Proposition 1 with regard to our 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 7.1 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 at the international level).

The assumption of cumulative innovation in case of imitation (regimes P and N), $v_i^N = v_i^P = 1 + \phi_i + \phi_j$, 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 Lai and Qiu (2003)

[23] 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).

and Grossman and Lai (2004). 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 Rey, 2003 and Valletti, 2006).[24]

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.[25] 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).

Appendix 8.5 explores the possibility that under regime P firm 2 obtains a patent on 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

[24] 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).

[25] 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).

innovation and welfare are preserved. In particular, Proposition 1 still holds, but the critical threshold value $\Delta(\gamma)$ is pushed up (i.e., the partial protection regime is preferred more often).

This section has shown that our base result on the impact of IPR on global innovation is robust to different variations of the model. We now decompose the result of Proposition 1 at the industry and country level in order to get testable implications.

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. Appendix 8.6 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. To compute the utilitarian welfare we need first to compute the national firm profit. We compare profits under the regime P (in the case of imitation) and F. The following preliminary 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. See Appendix 7.2. ■

We are now ready, by adding the national consumer's surplus to the national firm profit, to derive the optimal policy regarding IPR enforcement from the country 2 point of view.

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 $\Delta_2(\gamma) < \Delta_2'(\gamma)$.

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.

The result in Proposition 2 is the equilibrium if a lax enforcement of IPR leads to global trade sanctions on certain type of products/sectors so that firms in these sectors that would respect IPR would not be able to export. In practice, as explained in the introduction, both the EU (e.g., with Korea) and the US (e.g., with Brazil) have imposed global sanction on importations of countries which violated their IPR. They also destroy on a daily basis the commodities seized at the borders that are either counterfeit or infringing on IPR.

Now, if there is no global sectoral 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). When the regime chosen by country 2 is P, firm 2 imitates if and only if $\Pi_2^P \geq \Pi_2^F$. Since the thresholds $\underline{\gamma}$, $\overline{\gamma}$ are smaller than the thresholds $\underline{\gamma}'$ and $\overline{\gamma}'$ respectively, and since $\Delta_2(\gamma)$ is smaller than $\Delta_2'(\gamma)$, Proposition 2 implies 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 national firm. Note that, when anticipating this imitation choice, the country is indifferent between enforcing or not enforcing IPR in this region. Our conclusions are not affected although there is now a region of indifference in which the preference of country 2 for regime P becomes weak.

So far we have focused on a specific industry/sector $k \in K$. For the countries which do not have developed any real R&D capacity (i.e., so that $\Delta \rightarrow +\infty$ in all sectors), 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.[26] Now some developing countries have chosen to develop particular sectors, which, as a result, differ in their technological performance and $R\&D$ capacity from others. 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 public policy of piracy boosted the Indian pharmaceutical sector, making it able to address local market needs with surpluses that facilitated exports in direction of other developing countries, especially in Sub-Saharan Africa. 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 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.

If a country can choose differentiated IPR enforcement by sector, it will follow the result of Proposition 2 sector-wise. Firms in different sectors will behave differently, some of them imitating the Northern technology while other will choose to respect country 1 IPR to be able to export. This helps to explain 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 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). The exporters respect IPR to be able to sell their production. But the vast majority of Chinese manufacturing firms, which produces only for the Chinese market, are happily stealing technology from the North.

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 not solely

[26] 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 $k \in K$ depend on Δ_k. When $\Delta_k = \Delta$, $\forall k \in K$, then the optimal decision is the same in all sectors.

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 (see appendix 8.6). 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. This free-rider behavior should decrease with the maturity of the country's R&D system. This theoretical result is consistent with the existing empirical evidences: Braga et al. (2000) and Chen and Puttitanun (2005) find a robust U-shaped relation between IPR enforcement and economic development.

5.1 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.

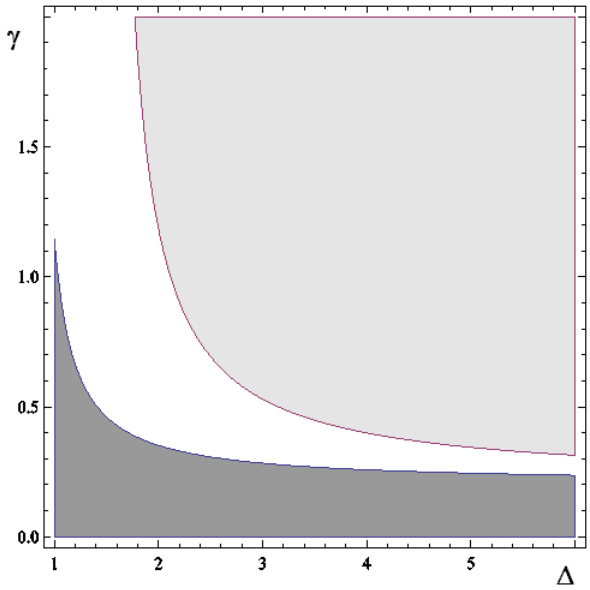

Figure 1: Welfare difference $W_i^F - W_i^P$. In the dark shaded region $W_2^F - W_2^P \geq 0$ and in the light shaded region $W_1^F - W_1^P \geq 0$.

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

5.2 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 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 on innovation has mostly focused on the pharmaceutical industry. 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. Auriol et al. (2017) looks empirically at the relation between stronger IPR protection and innovation in other sectors than pharmaceutical (i.e., in manufacturing). They 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 based in developed countries). The two effects cancel out when the two sets of patents are merged, which 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 ones.

6 Conclusion

The paper contributes to the understanding of the forces that can encourage 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 to export opportunities. At the country level there is a trade-off between the benefit of free-riding on the advanced economies innovations to serve the 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. The reverse is true if the internal market is relatively small. Rich countries have an incentive to protect IRP because they are big innovators. The analysis hence predicts that 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.

The paper also studies the impact of an asymmetric IPR regime on global innovation and compares it with a full protection regime. It shows that the 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 result is reversed. An asymmetric enforcement of IPR, weak in the South and strong in the North, often implies that the investment levels in R&D are higher than under a uniformly strong enforcement of IPR. Indeed under the former regime investments in R&D of Northern and Southern firms are strategic complement, while they are strategic substitute with a uniformly strong IPR regime. With asymmetric protection, developing countries are able to close their technological gap and investments by firms in the North are matched by investment by firm in the South such that total investment is larger than with universally strong protection and no technological diffusion.

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7 Appendix:

7.1 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:

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

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

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

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 (8) with the profit function being replaced by (13) and the quantity formula by (14), the socially optimal level of innovation in country i becomes:

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

  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:

  $$\phi^* = \frac{4(\Delta + 1)}{5\Delta - 4} - \frac{t}{\alpha b_1 b_2} \frac{2(\Delta + 1)}{5\Delta - 4} \quad (16)$$

  For $t = 0$, this corresponds to equation (9). 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:

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

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:

$$\phi_i^F = \frac{1}{2} \frac{\alpha(1 - \frac{\alpha}{3k_j})\frac{k_j}{k_1+k_2} - \frac{t}{k_1+k_2}(k_j(\frac{2}{b_j} - \frac{1}{b_i}) - \frac{4\alpha}{3b_j})}{\frac{9}{8}\frac{k_1k_2}{k_1+k_2} - \alpha(1 - \frac{\alpha}{3\frac{k_1+k_2}{2}})} \tag{18}$$

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 (10).

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.[27]

[27]Interestingly, the same effect does not occur when per capita revenue increases. Starting from a

The prospect of competing in a large foreign market increases the incentive to invest. On the contrary, when the foreign market is relatively small, a decrease in transportation costs tends to increase the negative impact 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 (5). 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

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.

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 (11). 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 (12). 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).

7.2 Proof of Lemma 1

The profits of firm 2 can be written:

$$\Pi_2^F = \frac{\alpha\Delta(9\Delta-4)}{(15\Delta-8)^2} \tag{30}$$

$$\Pi_2^P = \frac{\alpha 16\gamma\Delta(9(1+\gamma)\Delta-\gamma)}{(27\Delta+4\gamma(8\Delta-1))^2} \tag{31}$$

Comparing equation (30) with (31), 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

7.3 Proof of Proposition 2

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

$$W_i^F = \frac{1}{18}\left[3\alpha_i\left(2(1+\phi_i^F)^2 + (\phi_i^F - \phi_j^F)^2\right) + 2\alpha_j(1 + 2\phi_i^F - \phi_j^F)^2\right] - k_i\frac{(\phi_i^F)^2}{2} \tag{32}$$

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

$$W_2^F = \frac{\alpha(\gamma(\Delta(81\Delta-76)+18) + \Delta(9\Delta-4))}{(\gamma+1)(8-15\Delta)^2} \tag{33}$$

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

$$W_i^N = \frac{1}{9}(3\alpha_i + \alpha_j)(1 + \phi_1^N + \phi_2^N)^2 - k_i\frac{(\phi_i^N)^2}{2} \tag{34}$$

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:

$$W_2^N = \frac{\alpha\Delta(\gamma(27\Delta-1) + 9\Delta - 1)}{(\gamma+1)(1-8\Delta)^2} \tag{35}$$

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

$$W_2^P = \frac{1}{3}\alpha_2(1 + \phi_1^P + \phi_2^P)^2 - k_2\frac{(\phi_2^P)^2}{2} \tag{36}$$

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:

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

Using (33) and (37), we can write the welfare difference $W_2^F - W_2^P$ as:

$$\frac{W_2^F - W_2^P}{\alpha} = \frac{-16\Delta\gamma(27\Delta(1+\gamma)-\gamma)}{(\Delta(27+32\gamma)-4\gamma)^2} + \frac{\Delta(9\Delta(1+9\gamma)-76\gamma-4)+18\gamma}{(15\Delta-8)^2(1+\gamma)} \tag{38}$$

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

$$\frac{\partial(W_2^F - W_2^P)}{\partial\Delta} = -\alpha\left(\frac{12\Delta(13\gamma+7)-32-68\gamma}{(15\Delta-8)^3(1+\gamma)} - \frac{16\gamma^2(\Delta(189+184\gamma)-4\gamma)}{(\Delta(27+32\gamma)-4\gamma)^3}\right) \tag{39}$$

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.

Thresholds $\underline{\gamma}$ is lower than threshold $\underline{\gamma}'$ in Lemma 1 and threshold $\overline{\gamma}$ is lower than threshold $\overline{\gamma}'$. 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 1. The region defined by Lemma 1 has the same shape, but it is larger (the region defined by Lemma 1 has the same shape as in the dark-shaded region in Figure 1, but a frontier further from to the origin of the graph, i.e. 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 $i = 1$ is defined as in (32), and under no protection (N) it is defined as in (34), while under partial protection (P) it is:

$$W_1^P = \frac{1}{72}(27\alpha_1 + 8\alpha_2)(1 + \phi_1^P + \phi_2^P)^2 - k_1\frac{(\phi_1^P)^2}{2} \tag{40}$$

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

$$W_1^F = \frac{\alpha\,(5\gamma(2-3\Delta)^2 + 3\Delta(39\Delta - 44) + 38)}{(\gamma+1)(8-15\Delta)^2} \tag{41}$$

Under partial protection (P) it is:

$$W_1^P = \frac{\alpha(2\gamma(64\gamma + 279) + 405)\Delta^2}{(4\gamma(8\Delta - 1) + 27\Delta)^2} \tag{42}$$

Finally, under no protection (N) it is:

$$W_1^N = \frac{2\alpha(4\gamma + 13)\Delta^2}{(\gamma+1)(1-8\Delta)^2} \tag{43}$$

Comparing equation (41) with (42) one can check that:

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

Moreover,

$$\frac{\partial(W_1^F - W_1^P)}{\partial\Delta} = \frac{4\alpha}{5(\gamma+1)}(5\gamma\Big(\frac{2(\gamma+1)(2\gamma(64\gamma+279)+405)\Delta}{(4\gamma(8\Delta-1)+27\Delta)^3} + \frac{15(3\Delta-2)}{(15\Delta-8)^3}\Big) + \frac{15(9\Delta-7)}{(15\Delta-8)^3}\Big) \tag{44}$$

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:

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

and firm 1's investment is:

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

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

As intuition suggests, ϕ_{1d}^F increases and ϕ_{2d}^F decreases in d. Comparing equation (45) 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 (46) 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 ($\Delta \to \infty$).

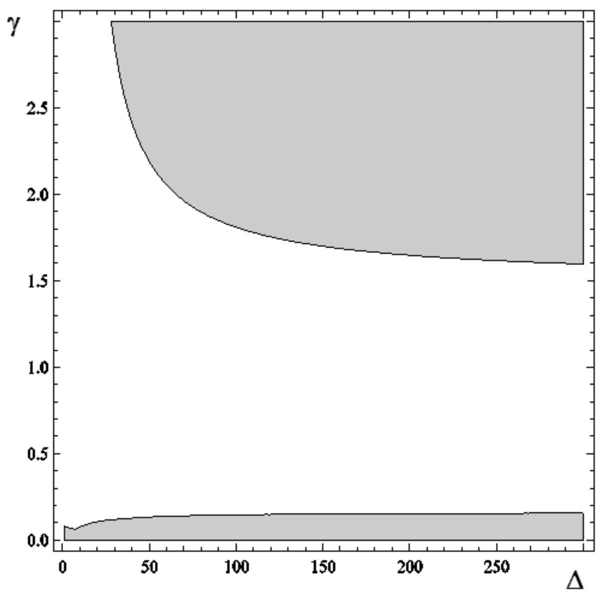


Figure 2: Total welfare difference: $(W_1^F + W_2^F) - (W_1^P + W_2^P)$. In the colored region $(W_1^F + W_2^F) - (W_1^P + W_2^P) > 0$.

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 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 in country 1 (because it is not too costly) 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 (32) 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:

$$k_1 = \underline{k}\alpha \tag{48}$$

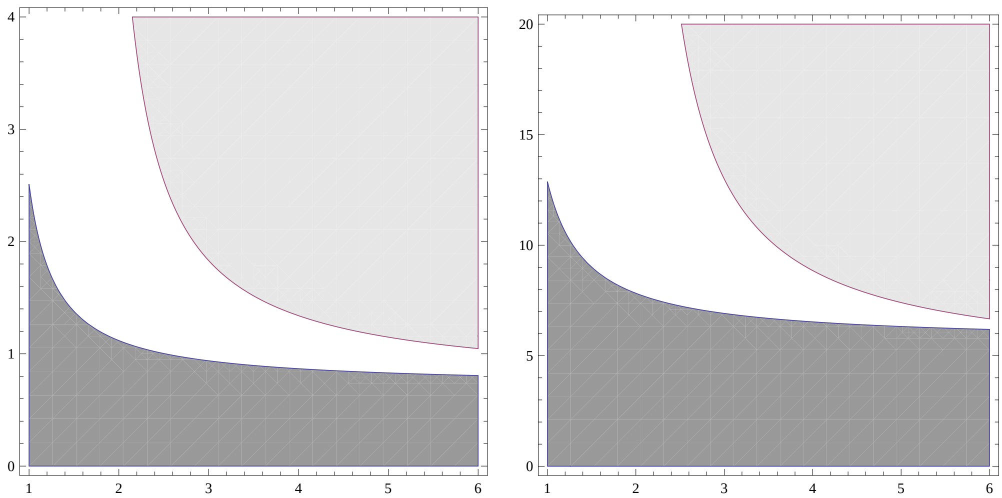
with $\underline{k} > 2$. In this case, the investment levels become:

$$\phi_{\underline{k}}^* = \frac{8(\Delta+1)}{(9\underline{k}-8)\Delta-8}$$
$$\phi_{\underline{k}}^F = \frac{4(3\underline{k}\Delta-4)}{3\underline{k}((9\underline{k}-8)\Delta-8)+16}$$
$$\phi_{\underline{k}}^P = \frac{9\Delta+4\gamma(\Delta+1)}{\Delta(18\underline{k}(1+\gamma)-4\gamma-9)-4\gamma}$$
$$\phi_{\underline{k}}^N = \frac{2(\Delta+1)}{(9\underline{k}-2)\Delta-2}$$

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:

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

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

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

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

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

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

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

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:

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

The profits under assumption 1 can be written as:

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

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

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

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:

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

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

Maximizing these profits we obtain the reaction functions:

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

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

Solving the system under assumption 1 we find:

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

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

$$\phi_f^P = \frac{\Delta\left((3+f)^2\gamma + 9f(f+2)\right) - f(9-(6+f)\gamma) + 9(1+\gamma+\Delta)}{4\Delta\left(2(3+f)^2\gamma + 9f + 18\right) + f(9-(6+f)\gamma) - 9(1+\gamma)} \tag{51}$$

Comparing equations (49) and (50) 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:

$$\phi_1^P(\phi_2) = \frac{2.25\alpha_1(1+g\phi_2) + (2-g)\alpha_2(1+(2g-1)\phi_2)}{4.5k_1 - (2.25\alpha_1 + (2-g)^2\alpha_2)} \tag{52}$$

$$\phi_2^P(\phi_1) = \frac{(2-g)\alpha_2(1+\phi_1(2g-1))}{4.5k_2 - (2-g)^2\alpha_2} \tag{53}$$

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

$$\phi_i^N(\phi_j) = \frac{\alpha(2-g)(1+(2g-1)\phi_j)}{4.5k_i - (2-g)^2\alpha} \tag{54}$$

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:

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

$$\phi_{2g}^P = \frac{4(2-g)\alpha_2((1-g)(3\alpha_1 + 2(2-g)\alpha_2) + 3k)}{54k^2\Delta - 3k\left(4(2-g)^2\alpha_2(\Delta+1) + 9\alpha_1\Delta\right) - 4(2-g)(1-g)(g+1)\alpha_2(3\alpha_1 - 2(2-g)\alpha_2)} \tag{56}$$

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

$$\phi_g^P = \frac{3\Delta(\gamma+1)(4(2-g)\gamma+9) - 6\left(g^3 - 5g + 2\right)\gamma - 4\left(4 - g^4 + 4g^3 - 10g\right)\gamma^2}{2(2-g)\gamma(3((2-g)g-3) - 2(2-g)(g^2+2)\gamma) + 3\Delta(\gamma+1)(4(5-g)(g+1)\gamma + 27)} \tag{57}$$

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

$$\phi_{ig}^N = \frac{2(2-g)\alpha(3k\Delta - 2(2-g)(1-g)\alpha)}{4\left(g^2-1\right)(g-2)^2\alpha^2 + 6(g-2)^2k(\Delta+1)\alpha - 27k^2\Delta} \tag{58}$$

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

$$\phi_g^N = \frac{3(2-g)\Delta - 4 + 10g + g^4 - 4g^3}{3(5-g)(g+1)\Delta - (2-g)^2\left(g^2+2\right)} \tag{59}$$

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 (57) and (59) 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.[28]

[28] 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.

8.5 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 (2) 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.

8.6 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 (41) and (43) to compute the welfare difference $W_1^P - W_1^N$:

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

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.

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

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 $\Delta \geq 1$:

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

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.