Intellectual Property Rights Adoption in Developing Countries

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Abstract

This paper studies the incentives that developing countries have to enforce intellectual properties rights (IPR). On the one hand, free-riding on rich countries technology reduces the investment cost in R&D. On the other hand, it yields a potential indirect cost: a firm that violates IPR cannot legally export in a country that enforces them. IPR act like a barrier to entry of the advanced economy markets. Moreover free-riders cannot prevent other to copy their own innovation. The analysis, which distinguishes between large and small developing countries, predicts that small ones should be willing to respect IPR if they want to export and access advanced economies markets, while large emerging countries, such as China and India, will be more reluctant to do so as their huge domestic markets develop. Global welfare is higher under the full protection regime if the developing country does not innovate. It is higher under a partial regime if both countries have access to similar R&D technology and the developing country market is large enough.

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1 Introduction

There has always been an international dimension to debates on intellectual property rights (IPR). However with the integration of the world economy and the liberalization and privatization of many formers state monopolies, which puts an end to public research in these sectors, IPR debates have become global. Amongst policy makers, a consensus emerged that "Western style" IPR legislation should be extended to every other country in the world. Contrary to Paris and Berne Conventions, that allowed considerable flexibility in the design of intellectual proterty regimes, TRIPS hence imposes a common framework for IPR. Their proponents argue that without global IPR innovations would stop in certain industries. In the absence of international patents, if a product takes considerable resources to be developed, but can be copied easily, firms will not have enough financial incentive to invest in R&D. The industries presumably more at risk are those that spend heavily on R&D (i.e., more than 5% of their sales revenue) such as pharmaceutical, computers, and communication equipments.

By contrast the detractors of universal IPR argue that they do not stimulate research to benefit the poor because they are not able to afford the high priced products if they are developed. Moreover they limit the possibility of technological learning through imitation, which has been found a key factor of the success of countries such as Taiwan, Korea, China or India in developing a world class capacity in many scientific and technological areas including space, nuclear energy, computing, biotechnology, pharmaceutical, software development and aviation. The following quote from Jeffrey Sachs in 2002 illustrates this position:

"In the Uruguay Round negotiation, the international pharmaceutical industry pushed very hard for a universal coverage of patent protection without considering the implications for the poorest countries. There is little doubt that the new IPR arrangements can make it more difficult for consumers in the poorest countries to access key technologies, as we've seen vividly in the case of essential medicines.... It also may well be the case that the tightening of IPRs may slow the diffusion of technology to the world's poorest countries that has traditionally come through copying and reverse engineering. Those hallowed pathways of technological diffusion are increasingly being slowed, and the effects on the

poorest countries may be unduly hindered. "

The economic literature on the impact of IPR is also rather inconclusive. It remains ambivalent as to whether the social benefits of IPR exceed their costs, even in relation to the developed world. The basic argument in favor of IPR is that they are necessary to stimulate invention and new technologies. The main critic against IPR is that they increase the cost of patented commodities which reduces welfare. This problem is exacerbated in developing countries because they are net importers of technology. Indeed innovative activities are concentrated in a handful of developed countries with top ten countries accounting for 84 per cent of global R&D activity. In the present paper we propose a simple framework in which the desirability of using strong IPR can be assessed.

The paper studies the impact of different IPR regimes on the investment decisions make by private firms in a two (heterogeneous) countries model. We assume that there is a firm producing a vertically differentiated commodity in each country. Innovation increases the quality of the commodity. This corresponds to a quality enhancing innovation, for instance a new generation of mobile phone. 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. More importantly we assume that countries differ in population size and per-capita income, which are both relevant demand characteristics. This specification allows us to cover different cases, including small, poor countries such as sub-saharan African countries, and large, poor countries such as China or India, competing with small or large, rich countries, such as Norway or the USA. This is new in the literature, where most papers focus on a uni-dimensional demand: high for rich countries and low for poor countries. The paper hence shows that taking into account the heterogeneity of developing countries is crucial for the welfare analysis of IPR. It is not the same to have a country like Benin to free ride on innovation or a country like China. The incentives of poor countries to adopt western style IPR differ depending on their capacity to innovate and on the size of their internal market.

In the model below imitation is costless but yields a potential indirect cost: a firm that violates IPR cannot export in a country that enforces them. Moreover if one country does not enforce IPRs, imitation occurs in both countries. There are thus benefits for a country which enforces IPR to compete with a country that does not enforce them: it can freely copy its competitor innovation, if any, while IPR act like a barrier to entry of its market. We show that independently of the level of efficiency of the national R&D process, of the size of the interior market and of the country wealth, aggregated investment level and welfare are always higher under a partial IPR protection regime than under a regime where there is no protection. One could argue that the no protection regime is not relevant because rich countries enforce IPR, so at worst partial enforcement regime holds. This is true only if parallel trade are banned. In the case of parallel imports, such as for instance the trade of drugs through the internet, the equilibrium is equivalent to the no protection situation. This equilibrium is very bad, both for investment and welfare.

Although this result suggests that more protection of IPR is better than less, a full protection of IPR is not always conducive of a higher level of investment. It depends on the capacity of each country to do R&D. In the asymmetric situation where only the rich country does R&D, it is true that when the foreign market is sizable, market integration with full patent protection guarantees the highest level of innovation. However this result is reversed if the market of the developing country is small. In this case enforcing strictly IPR in the poor country does not increase the incentives of the firm in the rich country to invest. As argued by their opponent, uniform IPR are not necessarily conductive of more investment at the global level, especially when applied to small, poor countries. Symmetrically when both countries have access to identical R&D technology, the global level of investment in the full protection regime converges toward the low level of the no protection regime. The total level of innovation is higher under a partial protection system. This result arises because investment in R&D boosts demand and market growth. In equilibrium the demand is enlarged so that the firm invests more in quality development. The investment level of the two competing firms are strategic complement.

From a policy perspective, it is not clear whether developing countries will have an incentive to adopt strong IPR regime, as requested by TRIPS, or not. Governments, which are negotiating agreements on IPR, focus on their domestic welfare. Starting from the premise that rich countries have already adopted them, we study the incentives that poor countries have to follow them. We show that when the R&D system is much more efficient in the rich country, the developing country chooses to protect IPR only when its domestic market is relatively small. In this case it is important for the poor country that wishes to export its production, to access the foreign market. This can happen only if it respects IPR. By contrast when the size of its national market is large, the developing country can afford not to protect IPR, even if this precludes its firm to legally export in rich country. The paper thus predicts that small developing country should be willing to respect IPR, while large emerging countries, such as China and India, might be very reluctant to do so.

It is not true that for the advanced economy the choice of not protecting IPR in the developing country is necessarily bad. If IPR are effectively respected in the rich country (i.e., by banning illegal imports), when the developing country chooses to steal the technology of the rich, this reduces competition in the latter market. At the same time, if the firm in the developing country also innovates and IPR are not protected, the firm in the advanced economy can include the innovations developed by its competitor in its own products. Incremental innovations made by firm in the poor country increase the stock of innovation offered by firm in the rich country, increasing in turn the demand for its products and thus its profit. Because of these competition and demand effects, the full protection regime is best for the rich country when the market of the poor country is large enough and the rich country has a technological advantage. Otherwise the rich country is better off with a partial regime. There is thus a potential conflict of interest between the countries. They fancy opposite policies in many cases. Reaching a consensus on IPR will be challenging.

Regarding global welfare, the full protection regime is always preferred if the developing country does not innovate. This result is consistant with the view expressed by the proponent of strong IPR regimes. When some large countries do not invest in R&D and totally free-ride on the investment made by others, the global level of investment in R&D and welfare decline. Yet, if its internal market is large, the developing country is harmed by enforcing IPR and prefers not to protect innovation. Although it would be socially desirable, enforcing IPR in the developing country is not an equilibrium. By contrast, the total welfare tends to be higher under a partial regime if both countries have access to similar R&D technology and the developing country market is large enough.

The rest of the paper is structured as follows. Section 2 reviews the related literature on IPR. Section 3 develops the model. Section 4 presents the benchmark case of a closed economy. The open economy is studied in section 5, which derives equilibrium investment levels under different regimes of IPR: none, partial, and full. The welfare analysis is conducted in section 6. Finally section 7 concludes.

2 Related Literature

Starting with the seminal paper of Grossman and Lai (2004), several macroeconomic papers have considered the intellectual property protection in a context of horizontal innovation with Dixit-Stiglitz preferences. These papers have a general equilibrium approach and assume that innovation generates an increase in variety. In all cases patents induce a static inefficiency due to monopoly pricing. Grossman and Lai (2004) looks at 2 heterogeneous countries: one identifying the North (high innovation, high demand) and the other the South (low innovation, small demand). They show that the Southern economy has a lower optimal level of protection at the Nash Equilibrium. Moreover patent policies are strategic substitutes so that the global equilibrium level of patent protection is inefficiently low at the equilibrium. Efficiency can hence require to increase the level of protection of both countries, but harmonization (i.e. equal patent duration and enforcement rate) is not necessary nor sufficient to achieve an efficient outcome. Lai and Qiu (2003) start from an equilibrium similar to Grossman and Lai (2004): the optimal level of protection is smaller in the South. The South is also in general worse off if the policies are harmonized, as preconized by TRIPS. However, a reduction of tariffs in the North can compensate for this loss and both countries will gain (even more than if North pays a transfer to the South). For the authors, these results prove the merits of multi-sectoral negotiations as in the GATT/WTO.

By contrast, our paper, which takes a partial equilibrium approach as common in the microeconomics literature, focuses on vertical innovation: innovation increases the quality of a product (and not the number of products). As in the papers cited above, we look at the choice of intellectual property protection made by firms in developed and developing countries. However, contrarily to the existing literature, we allow countries to differ both in size and income. The developing economy can be larger than the developed one (in terms of population), although poorer and generally endowed with a less efficient R&D technology. Innovation can expand the size of the markets and opens the possibility of conquering new large markets in developing regions. Contrarily to Grossman and Lai (2004) and Lai and Qiu (2003) we find that increasing the level of protection in the less developed one does not always increase global welfare. We show that an incomplete protection regime in which the emerging country does not protect innovation can be preferred and this regime does not need to decrease innovation.

Many papers on IPR study the impact of parallel imports on innovation. In the presence of parallel imports (or international exhaustion) the possibility to perform price discrimination is reduced. This may in turn weakens the incentive to innovate. This view is partially challenged by Grossman and Edwin (2008). Starting from the same framework as in Grossman and Lai (2004), they show that parallel imports induce the less innovative country from the South to increase its prices, because it internalizes the effect of low prices on the incentive to innovate of North's firms. Other papers find different results. For instance, Rey, considering price-regulated markets (i.e. pharmaceutical) argues that parallel trade impedes the most innovating country to accept high local prices to stimulate R&D when a partner has a lower willingness to accept price increases (less research-oriented). This has adverse effects on innovation. Similarly, Malueg and Schwartz (1994) and Valletti (2006) find that parallel trade also reduces the incentive to innovate, while Valletti and Szymanski (2006) show that parallel trade always reduces investment when price differentials are based on price elasticities (but it may increase it when they depends on idiosyncratic cost differences). Finally, Li and Maskus (2006) find that the distortions associated with parallel imports inhibit innovation. This can harm global welfare, depending on whether the manufacturer was deterring PI with a high wholesale price. If so, banning such trade would raise expected welfare.

Contrarily to these papers, we do not look to parallel imports, but to the impact of imitation and product market competition. However, we also identity the level of innovation obtained in the case of complete absence of enforcement of IPR in both countries. In this case, the imitated good can be sold in the country of origin (not by re-importers but by the imitator). Our results for this case confirm that innovation would be generally harmed, but we also show that innovation can be higher than in the case of closed economy, depending on the size of the developing economy.

In the growth literature, Aghion et al. (2001) look at the effects of both competition and imitation on innovation and growth. Contrarily to the classical Schumpeterian branch of endogenous growth theory, they claim that the incentive to perform R&D depends not on the rents of a successful innovator per se, but rather on the innovator's incremental rents (i.e. the difference between the rents of a successful innovator and an unsuccessful one). Then, a firm that is imitated may face a larger incentive to innovate, because it is now in neck-and-neck competition with a technologically equal rival. In our model, imitation may also stimulate innovation, but through a different channel. We allow the imitator to improve the innovator's technology. Innovation then expand the potential demand of both producers, giving incentives to each of them to build on the other's innovations. This is reminiscent of Bessen and Maskin, who consider a single country model and argue that when discoveries are "sequential" (so that each successive invention builds in an essential way on its predecessors) and "complementary" (potential innovator takes a different research line and thereby enhances the overall probability that a particular goal is reached) IPR protection is not as useful for encouraging innovation in a dynamic setting. Indeed, society and even inventors themselves may be better off without such protection. In our model, the total absence of protection generally harms innovation. However, the fact that the poorer country does not enforce IPR does not need to decrease innovation.

Saint-Paul (2003) studies an endogenous growth model where a profit-motivated R&D sector coexists with the introduction of free blueprints invented by philanthropists ("open source" innovations). He shows that philanthropy does not necessarily increase long-run growth and that it may even reduce welfare. The reason is that competition coming from philanthropists crowds out proprietary innovation which on net may reduce total innovation in the long run.

In our model, we concentrate on imitation. Competition from imitators also "steals business" from innovating firm. However we show that the competitive pressure introduced by imitators does not need to reduce the total level of innovation. This is for two reasons already evoked. First, when imitators have access to a large developing market, conquering new market shares can induce an increase in innovation activities even if this innovation is not protected in the foreign country. Second, we assume that innovation is incremental and imitators can build on established innovation contributing to increase the size of the market.

Anton and Yao (2004) analyze firms' choice of patenting innovation when information is asymmetric and IPR offer only limited protection. They start from the premise that patent related disclosure provides competitors with valuable information. They focus on the innovator's decision about how much of an innovation should be disclosed (their analysis starts when the innovation is discovered and all investment financed). They find that in equilibrium small innovations are patented and fully disclosed while large innovations are kept secret and partially disclosed through a public announcement. Encaoua and Lefouili (Forthcoming) extend the analysis to the case in which a patent reveals technological information that lowers the imitation cost relatively to the situation where the innovation is kept secret and they show the possibility of patenting some large process innovations whenever imitation is too costly.

In our paper, we restrict the attention to complete information. Still, the characteristics of the innovating technology and the consequent size of innovations play a role in the analysis. We explicitly model the initial investment stage and we show that the structure of R&D costs affects the equilibrium size of the innovations. As a consequence, countries can choose different protection regimes depending on the characteristics of $R\&D$ costs in the sector. When R&D is very costly in both countries and innovations are small, imitation also becomes less profitable and the less innovative country prefers to protect IPR to be allowed to exports its goods in the developed economy (where IPR are well established). When the cost of innovation is very asymmetric and the size of the developing country is large, imitation is protected less often. However, this does not always harm investment (although it can reduce welfare in the most innovating economy).

3 The model

We consider a two countries economy. There is a firm producing a vertically differentiated commodity in each country. Index $i = 1, 2$ thus refers indifferently to country i or commodity i. Countries differ in population size and per-capita income, which are relevant demand characteristics. In the case of a closed economy, demand in country $i = 1, 2$ is:

$$p_i = a_i(v_i - b_i q_i) \tag{1}$$

where v_i represents the quality and q_i the quantity of good i. In this "quality augmented" linear demand,[1] a_i should be interpreted as the per-capita income and b_i as the *inverse* of the population size of country i.[2] This specification allows us to cover different cases, including small, poor countries (e.g., sub-saharan African countries) and large, poor countries (e.g., China or India) competing with small and large, rich countries (e.g. Norway and USA). A parameter which plays an important role in the analysis below is the ratio $\frac{a_i}{b_i}$. Let define

$$\alpha_i = \frac{a_i}{b_i}. \tag{2}$$

This parameter reflects the intensity of the demand in country i. It is worth noticing that there is no clear relationship between α_i and development. A poorer (i.e. lower a_i) but more populated country (i.e., higher $\frac{1}{b_i}$) can have a higher α_i than richer but smaller country. For instance the interior market of China is bigger than the interior market of Finland. The model allows us to capture the heterogeneity of both advanced economies and developing countries.

In a closed economy each firm is in a monopoly position in its respective market. However when the market is integrated, there is a duopoly in each country. Demand for good i in country j then writes:

$$p_{ij} = a_j(v_i - b_j(q_{1j} + q_{2j})) \qquad i, j \in \{1, 2\} \tag{3}$$

where q_{ij} is the quantity of good i sold in country j. When goods have the same quality, they are perfect substitutes. They are not if the varieties produced by the two firms differ.

[1] For a discussion of quality augmented models, see Singh and Vives (1984).

[2] To see this, assume that the indirect utility of a representative consumer consuming a good of quality v is given by: $V(y, q) = u(y) + vq + \frac{q^2}{2}$ where q is the quantity and y is the net income $y = I - pq$. Solving the consumer's problem, we obtain $p = \frac{1}{u'(I-pq)}(v - q)$. Then, for pq small, $u'(I - pq)$ is closed to the marginal utility of income and the (inverse) demand of a representative consumer can be written: $p = a(v - q)$, with $a \equiv \frac{1}{u'(I-pq)}$. Then, the demand of a representative consumer can be written: $q = v - \frac{1}{a}p$ and total demand $Q = Nv - \frac{N}{a}p$ where N is the size of the population. We let $b \equiv \frac{1}{N}$ and we write: $P = a(v - bQ)$. We now denote the price in country i $P = p_i$ and the total quantity in country i $Q = q_i$, obtaining the notation of Equation (1).

We set the common level of quality before investment to 1. We assume that innovation increases the quality of the commodity by ϕ_i. This corresponds to a quality enhancing innovation, for instance a new generation of mobile phone. The cost of the R&D investment is $k_i\frac{\phi_i^2}{2}$, where k_i is an inverse measure of the efficiency of the $R\&D$ process in country $i = 1, 2$. That is, a larger k_i corresponds to a less efficient R&D process. By investing $k_i\frac{\phi_i^2}{2}$ a firm increases the quality of the good from $v_i^{NI} = 1$ to $v_i^I = 1 + \phi_i$. Innovation is thus deterministic. This assumption simplifies the exposition without altering the results of the paper. If innovation was stochastic so that the probability of improving the quality was increasing with the amount invested, the same qualitative results would hold. Finally once a quality is developed, the marginal cost of productions are normalized to zero for both firms. Alternatively, we could define p_{ij} the price net of marginal cost of firm i, c_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 c_i. It can be shown that this alternative model gives similar qualitative results.

We also make the following technical assumption:

Assumption 1

$$k_2 > k_1 > \frac{16}{9}\Big(\alpha_2 + \alpha_1\Big)$$

The first part of assumption 1 (i.e., $k_2 > k_1$) simply states that country 1, typically a rich country, has a better R&D system than countries 2, a poor country. This is done without any loss of generality. The second part of assumption 1 (i.e., $k_1 > \frac{16}{9}(\alpha_2 + \alpha_1)$) guarantees that our maximization problems are concave, which allows to easily characterize the optimal levels of investment in all cases.

4 Closed economy

In the benchmark case of a closed economy, there is a monopoly in each country. The firms maximize their profit with respect to the level of investment in R&D, ϕ_i (the level of quality then is $v_i = 1 + \phi_i$), and the quantity, q_i $(i = 1, 2)$.

$$\Pi_i^M = p_i q_i - k_i\frac{\phi_i^2}{2} = a_i(1 + \phi_i - b_i q_i)q_i - k_i\frac{\phi_i^2}{2} \qquad i \in \{1, 2\} \tag{4}$$

It is straightforward to check that under assumption 1, the profit function is concave in q_i and ϕ_i. The first order conditions (FOC) are sufficient. We deduce easily that in a closed economy the private monopoly $i = 1, 2$ chooses the investment level:

$$\phi_i^M = \frac{\alpha_i}{2k_i - \alpha_i} \tag{5}$$

and the quantity:

$$q_i^M = \frac{1 + \phi_i}{2b_i}. \tag{6}$$

Under assumption 1 one can check that $\phi_i^M > 0$. Since this level of investment is chosen by a monopoly it is unlikely to be efficient. We compute next the level of investment that a benevolent planner would choose, taking into account the patent right of the private firm (i.e., the monopoly power of the firm over price). The social planner maximizes with respect to ϕ_i:

$$W_i = S_i^M + \Pi_i^M \tag{7}$$

Where S_i^M is consumer surplus $S_i = \frac{1}{2}(av_i - P_i(q_i))q_i$ evaluated at $q_i^M = \frac{1+\phi_i}{2b_i}$:

$$S_i^M = \frac{\alpha_i}{8}(1 + \phi_i)^2$$

and Π_i is the profit of the firm:

$$\Pi_i^M = \frac{\alpha_i}{4}(1 + \phi_i)^2 - k_i \frac{\phi_i^2}{2} \tag{8}$$

Maximizing (7) with respect to ϕ_i we obtain:

$$\phi_i^{M*} = \frac{\alpha_i}{\frac{4}{3}k_i - \alpha_i} \tag{9}$$

Comparing equations (5) and (9), it is straightforward to check that the level of investment chosen by a private monopoly is lower than the level chosen by a welfare maximizing social planner in the closed economy. The regulator pushes investment up because in this way she partially offsets the under provision in quantities due to monopoly pricing.

5 Market integration

In the common market, firms compete in both countries. The timing is as follows: In the first stage, firms invest in $R\&D$ and the quality of the goods is determined. In the second stage, they compete in quantities. Then, the level of protection of the innovation activity influences investment. If both countries protects intellectual property rights (IPR), imitation is not allowed. Each firm can privately exploits the benefits of its *R&D* activity. On the other hand, if one or both countries do not enforce IPRs, imitation occurs in *both* countries. Indeed if country i strictly enforces its property rights, it can still copy the innovation of country j as long as j is not enforcing IPR. Similarly the firm in country j can imitate the innovation invented in i without paying the investment cost if there is no IPR in j. For simplicity, we assume that imitation is costless. We distinguish among three possible regimes:

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 protects innovation. Firm 2 imitates, but it can also invest in incremental innovation. However, because Firm 2 violates the patents protected in 1, it will not be able to sell in 1, but only in country 2, where patents are not enforced (we neglect the possibility of illegal imports). We assume that firm 1 can reproduce the incremental technological improvement developed by Firm 2. Firm 2 free-rides on the innovation of firm 1 but it cannot, in turn, prevents firm 1 to use its own innovation. We have $v_i^P = v_i^N = 1 + \phi_i + \phi_j$.

After market integration, each country becomes a duopoly, denoted D, except in the partial regime (P) where the country which enforces strictly IPR forbids importation by the imitator, and thus stay a monopoly. We assume that exporting in a foreign country implies a unit transportation cost equal to $t \geq 0$. At the second stage, the quantity produced by firm i in country j is the Cournot quantity:

$$q_{ij}^D = \frac{2v_i^I - v_{-i}^I}{3b_j} + \frac{2t}{3a_i b_j} \;, \qquad i, -i, j \in \{1, 2\}, i \neq -i \tag{10}$$

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 total profit of firm i writes:

$$\Pi_i^D = p_{i1}q_{i1} + p_{i2}q_{i2} - k_i\frac{\phi_i^2}{2} \tag{11}$$

And welfare of country j:

$$W_j^D = S_j^D + \Pi_j^D \tag{12}$$

where:

$$S_j^D = a_j(v_1q_{1j} + v_2q_{2j}) - a_jb_j\frac{(q_{1j}+q_{2j})^2}{2} - p_{1j}q_{1j} - p_{2j}q_{2j}$$

When the market is integrated, innovation allows to increase profits and welfare in both countries. Moreover the level of investment chosen by firm i will depend on the level of firm $-i$.

5.1 The socially optimal level of investment:

We start by computing the optimal level of innovation in the common market, taking into account the firms market power (i.e., property right). The optimal investment is the level chosen by a centralized authority maximizing total welfare:

$$W = W_1^D + W_2^D \tag{13}$$

A supranational social planner always chooses full disclosure of innovation (i.e. the no protection regime N). Once the cost of $R\&D$ is paid, she has no reason to limit its diffusion. The socially optimal level of innovation in country i is thus obtained maximizing (13) with respect to ϕ_i and ϕ_j ($i \neq j$). This gives:

$$\phi_i^* = \frac{(\alpha_1+\alpha_2) - t\frac{b_1+b_2}{2b_1b_2}}{\frac{9}{8}\frac{k_1k_2}{k_1+k_2} - (\alpha_1+\alpha_2)}\ \frac{k_j}{k_1+k_2} \tag{14}$$

and

$$\phi_t^* = \phi_1^* + \phi_2^* = \frac{(\alpha_1+\alpha_2) - t\frac{b_1+b_2}{2b_1b_2}}{\frac{9}{8}\frac{k_1k_2}{k_1+k_2} - (\alpha_1+\alpha_2)} \tag{15}$$

The optimal level of investment of equation (15) is somehow a generalization of equation (9) to the duopoly case with transportation cost. Indeed let consider the case where transportation costs are negligible (i.e., $t = 0$). The optimal investment level is:

$$\phi^* = \frac{(\alpha_1 + \alpha_2)}{\frac{9}{8}\frac{k_1 k_2}{k_1 + k_2} - (\alpha_1 + \alpha_2)}. \tag{16}$$

We now turn to the study of the equilibrium level of investment in country 1 and 2. The private level of investment chosen by firms 1 and 2 depends on the IPR regime. In case of full protection, firms cannot free-ride on each other investment. Investment costs need to be duplicated to obtain the same level of quality in both countries. We consider the three IPR regimes separately.

5.2 Full IPR protection (F regime)

In the case of full IPR protection, the quality of good i after investment is given by $\phi_i^F = \phi_i$. At the second stage (quantity competition), quantities are given by the Cournot levels in (10). At the first stage (investment stage), Firm i maximizes the profit (11) with respect to ϕ_i, for a given level of ϕ_j, $i \neq j$. Profit maximization gives the reaction function:

$$\phi_i(\phi_j) = \frac{(\alpha_1 + \alpha_2)(1 - \phi_j) - \frac{2b_i - b_j}{b_i b_j} t}{2.25 k_i - 2(\alpha_1 + \alpha_2)} \tag{17}$$

We first notice that 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, quality i becomes more valuable to the consumer. Other things being equal, this decreases the demand for good j and so firm j's incentive to innovate. This is a pure competition effect that passes through substitution. When the goods have different qualities, they are not perfect substitutes. 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.[3]

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

[3] In the alternative version of the model in which innovation decreases costs, the same effect arises. Without imitation, innovation by firm i makes this firms more efficient than j. This increases its demand and decreases the one of the competitor (and its incentive to innovate).

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 $t > 0$, an increase in the relative size of demand i (i.e. $b_j - b_i$) shifts the reaction function of firm i upwards. As a consequence, at the equilibrium firm i invests more than firm j if and only if $b_i < b_j$ (i.e. the country i has a larger demand size). Then, when exports are costly, the size of the internal market matters. Firms in larger markets invest more than competitors operating in smaller ones, even when trade is allowed and firms can sell their product abroad. Interestingly, this does not occur when per-capita revenue are asymmetric ($a_i \neq a_j$). If the revenue of a country increases, both firms invest more, but the investment levels remains 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.

Solving the system of first order conditions, we obtain:

$$\phi_i^F = \frac{1}{2}\frac{(\alpha_1+\alpha_2)(1-\frac{\alpha_1+\alpha_2}{3k_j})\frac{k_j}{k_1+k_2} - \frac{t}{k_1+k_2}(k_j(\frac{2}{b_j}-\frac{1}{b_i}) - \frac{4(\alpha_1+\alpha_2)}{3b_j})}{\frac{9}{8}\frac{k_1k_2}{k_1+k_2} - (\alpha_1+\alpha_2)(1-\frac{\alpha_1+\alpha_2}{3\frac{k_1+k_2}{2}})} \tag{18}$$

As expected, the level of quality chosen by firm i depends negatively on k_i (measuring the efficiency of own R&D technology) 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:

$$\frac{b_j}{b_i} \leq 2 - \frac{4}{3}\frac{\alpha_1+\alpha_2}{k_j} \tag{19}$$

Then, 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 (remember that the parameter b is related to the inverse of population size). In this case, the perspective of competing in a large foreign market increases the incentive to invest. On the contrary, when the foreign market is relatively small, decreasing the transportation cost has the main effect of increasing the negative impact of competition on domestic profits, thus reducing the level of investment. Inequality (22) is easier to satisfy when k_j increases. The larger is the competitive disadvantage of firm i in terms of R&D technology, the more likely is that a reduction in transportation costs increases the incentive to invest of firm i in order to win market shares abroad.

5.3 No IPR protection (N regime)

When IPR are not protected, firms can imitate the innovations of competitors at no cost. 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 (10). At the first stage, profit maximization gives the reaction functions:

$$\phi_i(\phi_j) = \frac{(\alpha_1 + \alpha_2)(1 + \phi_j) - \frac{2b_i - b_j}{b_i b_j} t}{4.5k_i - (\alpha_1 + \alpha_2)} \tag{20}$$

In this case the slope of the reaction function is positive (quality levels and thus investment are strategic complements).

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

This result is counter-intuitive. 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 the firms can free ride on each other. Yet usually free-riding problems are associated to under investment. When the firms can exploit the innovations developed by their competitors without loosing the benefit of their own innovations, to win market shares they tend to invest more when their competitor invests more. Quality levels are hence strategic complements. Because of imitation, when firm i innovates this has a positive impact on the demand for good j as well. The size of the market for the two goods is increased. Then, the incentive of j to innovate is also enhanced. This effect depends on our assumption that innovation is cumulative and each firm can build on the innovation developed by the competitor.[4]

The role played by the transportation cost is equivalent than in the F case. When the transportation cost is positive, countries with larger population tend to invest more than smaller ones (everything else being equal). We have:

$$\phi_i^N = \frac{(\alpha_1 + \alpha_2)\frac{k_j}{k_1 + k_2} - \frac{t}{k_1 + k_2}\left(k_j\left(\frac{2}{b_j} - \frac{1}{b_i}\right) - \frac{2}{3}(\alpha_1 + \alpha_2)\left(\frac{1}{b_j} - \frac{1}{b_i}\right)\right)}{4.5\frac{k_1 k_2}{k_1 + k_2} - (\alpha_1 + \alpha_2)} \tag{21}$$

[4]In the alternative version of the model in which innovation decreases costs, the same effect would arise. With imitation, innovation by firm i makes both firms more efficient. This increases net demand of both firms and thus the incentive to innovate.

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:

$$\frac{b_j}{b_i} \leq \frac{2(3k_j - (\alpha_1 + \alpha_2))}{3k_j - 2(\alpha_1 + \alpha_2)} \tag{22}$$

Then, a decrease of the transportation cost increases the level of investment of country i if and only if country j is relatively large. Once again, the perspective of competing in a large foreign market increases the incentive to invests. However, contrarily to the case of (F) regime studied above, inequality (22) is more difficult to satisfy when k_j increases. The larger is the competitive advantage of firm i in terms of R&D technology, the less likely is that a reduction in transportation costs increases the incentive to invest in order to win market shares abroad. The reason is that when IPR are not protected the competitor can free-ride on investment and, the lower the transportation cost, the larger the negative impact of more efficient competition on domestic profits.

We deduce that:

$$\phi^N = \phi_1^N + \phi_2^N = \frac{(\alpha_1 + \alpha_2) - \frac{t}{k_1+k_2}(k_1(\frac{1}{b_2} - \frac{2}{b_1}) + k_2(\frac{1}{b_1} - \frac{2}{b_2}))}{4.5\frac{k_1 k_2}{k_1+k_2} - (\alpha_1 + \alpha_2)}. \tag{23}$$

Then, a decrease of the transportation cost increases the total level of investment if and only the two countries have sufficiently different sizes.

5.4 IPR protection only in one country (P regime)

When only one country protects IPR, foreign firms can imitate the innovation. The quality of good i after investment is given by $\phi^P = \phi_1^P + \phi_2^P$. Moreover both firms can sell in the market in which IPR are not protected. Indeed, IPR is usually well established in developed countries, while less developed ones have lower incentives/capacity to protect them. If country 1 protects IPR, imitated goods cannot be exported in 1 (we assume that illegal imports are banned). Then, if firm 2 chooses imitation, it will sell only in country 2. Then, firm 1 is a monopoly in country 1 and compete with 2 à la Cournot in country 2. At the second stage quantities are given by the Cournot levels in (10). At the first stage, profit maximization gives the reaction functions:

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

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

In the case of partial enforcement of IPR, investments are strategic complements. That is, the slope of reaction function is positive for both firms:

$$\frac{\partial \phi_i(\phi_j)}{\partial \phi_j} > 0 \quad i,j = 1,2 \; i \neq j.$$

However 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 investment of firm 1, that it free-rides, expands its 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.

We have:

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

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

We deduce that the total level of investment under the partial protection IPR regime is :

$$\phi^P = \phi_1^P + \phi_2^P = \frac{(\alpha_1 \frac{2.25k_2}{k_1+k_2} + \alpha_2) - \frac{4t}{b_2(k_1+k_2)}(2k_2 - k_1)}{4.5\frac{k_1k_2}{k_1+k_2} - (\alpha_1 \frac{2.25k_2}{k_1+k_2} + \alpha_2)} \tag{28}$$

We see that ϕ_1^P always increases when the transportation cost decreases, while ϕ_2^P decreases. Then, the transportation cost reduces the incentives to invest in R&D of the exporting firm. With higher transportation cost it is less profitable to export, and thus to invest in quality improvement. By contrast transportation cost *increases* the incentive to invest of the free-rider. Indeed transportation cost acts as a natural barrier to entry. The larger the transportation cost t and the interior market 2 (i.e., the larger $\frac{1}{b_2}$) are, the bigger is the demand of firm 2, which as a result has a higher incentive to invest in quality improvement. As a whole, the level of innovation ϕ^P increases when the transportation cost decreases.

In what follows we compare the different levels of investment achieved under the IPR regimes, F, N and P, studied above.

5.5 Investment levels under different IPR regimes

We are now ready to compare the total levels of innovation under the different protection regimes. For simplicity, in the following we restrict the attention to the case where transportation costs are negligible (i.e., $t = 0$). The role of transportation cost has been highlighted in the previous subsections. Comparing equations (18) with (14), one can check that under assumption 1 the levels of investment in R&D are suboptimal in the case of full protection of IPR: $\phi_2^F < \phi_1^F < \phi^*$. This is worse for the less efficient country. This result is hardly surprising because firms maximize their profit, not the social welfare of their investment in research. Similarly, comparing the level of investment committed in the absence of property right protection, (23), with the optimal level of investment (14), the level of investment is suboptimal in (N): $\phi^N < \phi^*$. Despite the fact that the free flow of innovations stimulates demand and thus encourages firms to invest more in innovation, firms under-invest in R&D compared to the optimum.

A more interesting issue is whether a weaker enforcement of the IPR regime degrades the equilibrium level of investment level, or on the contrary improves it. We can now establish a first general result.

Proposition 1 *Under Assumption 1 we have:*

$$\phi^* > \phi^P > \phi^N \tag{29}$$

Proof. Comparing equation (23) with (28) and letting $t = 0$, it is straightforward to check that $\phi^P > \phi^N$ is equivalent to $\alpha_1 \frac{2.25k_2}{k_1+k_2} + \alpha_2 > \alpha_1 + \alpha_2$, which is always trues since $k_2 > k_1$. Comparing next equation (14) with (28), $\phi^P < \phi^*$ is equivalent to $1.125(\alpha_1 \frac{2.25k_2}{k_1+k_2} + \alpha_2) < 4.5(\alpha_1 + \alpha_2)$. This inequality is always true because $\frac{2.25k_2}{k_1+k_2} \leq 2.25$ under the assumption $k_2 > k_1 \geq 0$. ■

We have shown earlier that the innovation level is always suboptimal: ϕ^* is larger than all the equilibrium values, $\phi_i^M, \phi_i^F, \phi^N, \phi^P$, obtained both under closed and open economy. Market opening and IPR policies have an impact on the investment activities. We would like to know which framework is the most conducive of a high level of investment. Independently of the level of efficiency of the national R&D process, of the size of the interior market (i.e., of the population) and of the country wealth, aggregated investment level is always higher under a partial IPR protection regime than under a regime where there is no protection at all. It tends to suggest, as it is often argued by the proponent of strong enforcement of IPR policies that, the more protection of IPR there is, the better it is for global investment. In what follow we show that it is not always the case. In particular the results very much depends on the capacity of each country to do R&D.

In order to compare the different innovation regimes, we make the following simplifying assumption, which allows to compare analytically the levels of innovations:

Assumption 2

$$k_1 = 2\Big(\alpha_2 + \alpha_1\Big)$$

Assumption 2 corresponds to fixing k_1 "small". It can be shown that when k_1 (and thus k_2) are very large, Country 2 is always better off under (F) (see section 6.1). Indeed, when $R\&D$ is very costly in both countries, only minor innovations take place. As a consequence, country 2 always prefers to protect IPR (and thus having firm 2 being allowed to export in country 1) compared to the situation where it enjoys marginal innovations only in its domestic market. Free-riding on country 1 innovation is never worthwhile. Country 2 always chooses the (F) IPR regime to be able to sell its own production in country 1. Indeed, when k_1 is too large innovation does not matter in the model, and the regimes (F) and (P) only differ in the possibility of exerting market power in one or both markets. Since we are interested in the role of innovation activities, we thus concentrate on small k_1, for which innovation matters and (P) can be an equilibrium. Assumption 1 tells us that k_1 must be higher than $16/9\Big(\alpha_2 + \alpha_1\Big)$. Then, Assumption 2 just fixes k_1 close to this minimum value. By continuity, other values sufficiently closed to $2\Big(\alpha_2+\alpha_1\Big)$ give the same qualitative results.

Moreover, let

$$k_2 = \Delta k_1 \ , \ \Delta > 1$$

$$\alpha_2 = \gamma \alpha_1 \ , \ \gamma > 0$$

Then, Δ captures the cost inefficiency of the least efficient firm 2 and γ the relative intensity of demand in country 2.

When $\Delta \to \infty$, only the more developed country, by convention country 1, invests. In many sectors, the innovation activity of less developed countries is still negligible. Innovative activities are concentrated in a handful of developed countries with top ten countries accounting for 84 per cent of global R&D activity. Many poor countries do not conduct research at all. When $\Delta \to \infty$ we thus assume that the country 2 is less developed and that firm 2 does not invest in R&D. On the contrary, when $\Delta \to 1$, the investment cost of the two countries converges to the same level. For instance, emerging economies, such as China and India, have developed very powerful and efficient R&D systems. When $1 < \Delta < \infty$, both countries invest, but country 2 has a less efficient technology.

Under Assumption 2 we can rewrite the relevant innovation levels. Under regime (P) we have

$$\phi_1^F = \frac{6\Delta - 4}{15\Delta - 8} \tag{30}$$

$$\phi_2^F = \frac{2}{15\Delta - 8} \tag{31}$$

As the equations show, the investment levels do not depend on γ (i.e. the ratio α_1/α_2). The reason is that, under Assumption 2, the model is normalized such that the cost parameters k_1 and k_2 increase proportionally to the total intensity of demand (i.e. $\alpha_1 + \alpha_2$). The total intensity of demand $\alpha_1 + \alpha_2$ does not matter (i.e. it is hidden by the normalization) and only the relative sizes of the market do.
Then, ϕ_1^F and ϕ_2^F only depend on the relative efficiency of the innovation technology (captured by Δ) and on the total size of the market (i.e. $\alpha_1 + \alpha_2$ which do not appear in the equation because of the normalization).
Similarly, under regime (N):

$$\phi_1^N = \frac{\Delta}{8\Delta - 1} \tag{32}$$

$$\phi_2^N = \frac{1}{8\Delta - 1} \tag{33}$$

$$\phi^N = \frac{\Delta + 1}{8\Delta - 1} \tag{34}$$

Under regime (P):

$$\phi_1^P = \frac{(9+4\gamma)\Delta}{27\Delta+4\gamma(8\Delta-1)} \quad (35)$$

$$\phi_2^P = \frac{4\gamma}{27\Delta+4\gamma(8\Delta-1)} \quad (36)$$

$$\phi^P = \frac{9\Delta+4\gamma(1+\Delta)}{27\Delta+4\gamma(8\Delta-1)} \quad (37)$$

In this case, the level of investment depends on the relative size of the two markets. Firm 2 imitates the innovation of firm 1 and is allowed to sell only in market 2. On the contrary, firm as a monopoly in market 1. Then, the incentives to invest depend on the relative size of the two markets. It is easy to check that investment of firm 2 increases more when γ increases (i.e. $\frac{\partial \phi_1^P}{\partial \gamma} \geq \frac{\partial \phi_2^P}{\partial \gamma} \geq 0$).

We also compute the monopoly innovation level:

$$\phi_1^M = \frac{1}{3+4\gamma} \quad (38)$$

$$\phi_2^M = \frac{\gamma}{4(1+\gamma)\Delta-\gamma} \quad (39)$$

Notice that, due to the normalization in Assumption 2, innovation in country 1 depends negatively on γ (an increase in γ can be interpreted as a reduction of the relative size of Country 1, when the $R\&D$ parameter k_1 is a fixed and proportional to the total size of the economy $\alpha_1+\alpha_2$). On the contrary, an increase in γ increases innovation in country 2, because the relative size of market 2 increases.

We first compare the equilibrium level of innovation under the three regimes (F), (P) and (N) with the one realized under monopoly (M). First of all, $\phi_i^F \geq \phi^M$ if and only if :

$$\Delta \geq \frac{4+16\gamma}{3+24\gamma}$$

Then, when $\Delta \to \infty$ (i.e. only country 1 invests), this is always satisfied. However, when Δ becomes smaller, this is satisfied only if γ is not too small. For instance, if $\Delta \to 1$, the inequality is satisfied if and only if $\gamma \geq \frac{1}{8}$.

Second, $\phi_i^N \geq \phi^M$ if and only if :

$$\Delta \leq \frac{4(1+\gamma)}{5-4\gamma}$$

Then, when $\Delta \rightarrow \infty$ (i.e. only country 1 invests), this is never satisfied. However, when Δ become smaller, this can satisfied if γ is large. For instance, if $\Delta \rightarrow 1$, the inequality is satisfied if and only if $\gamma \geq \frac{5}{4}$. Then, even if after market opening the innovation can be easily imitated, this does not necessary reduce the incentives to invest of innovation of the national firm. In particular, investment increases when α_2/α_1 is large enough. This would describe a foreign market which is seizable (i.e., a population which is not too poor and/or large enough). Conquering this kinds of markets pushes to increase innovation, even when innovation can be imitated and reimported (as in the case of no enforcement of IPR or the existence of parallel trade).

Finally, ϕ^P is always larger than ϕ_1^M (naturally $\phi_1^P \geq \phi_1^M$ and $\phi_2^P \leq \phi_2^M$).

We can now compare directly the investment regimes (F), (N) and (P).

Proposition 2 *Under Assumption 2, there exists a threshold $\hat{\Delta}(\gamma) \in (0, \infty)$ such that:*

- *If $\Delta \leq \hat{\Delta}(\gamma)$:*

$$\phi^N \leq \phi^F \leq \phi^P \leq \phi^*$$

- *If $\Delta > \hat{\Delta}(\gamma)$:*

$$\phi^N \leq \phi^P < \phi^F \leq \phi^*$$

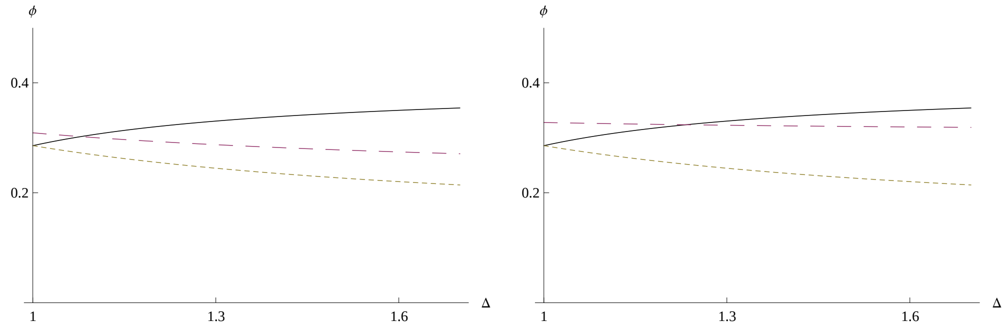
Moreover, $\hat{\Delta}(\gamma)$ is decreasing in γ.

Proof. The proof is in the appendix. ■

When only country 1 invests ($\Delta \rightarrow \infty$), market integration without strong IPR yields a low level of investment compared to stronger IPR regimes. In other words, market integration with full patent protection (F) guarantees the highest level of innovation. On the contrary, when $\Delta \rightarrow 1$, the solution in an open economy with negligible transportation cost is symmetric for the two firms. Interestingly the global level of investment in the F regime converges toward the low level of the N regime. To be more specific, one can check that $\phi^F = \phi^N$ when $\Delta \to 1$. The total level of innovation is higher (i.e., it is closer to the first best level) under a partial protection system (P) than under a full protection system (F). When the firm in country 2 also develops an efficient $R\&D$ technology and invests significantly, innovation is higher if country 2 does not protect IPR. In this case the investment level of the two competing firms are strategic complement, and an increase of investment by firm in country 1 is matched by an increase in investment by firm in country 2. This result arises because investment in R&D boosts demand and market growth. In the Nash equilibrium played by the two competing firms, the level invested by the competitor is exogenous. It is a demand booster when the result of the R&D can be copied. In equilibrium the demand is larger so that the firm invests more in quality development. When the technologies becomes very similar ($k_2 \to k_1$), the level of investment under full protection (F) converges to the level of full imitation (N). In this case, imitation would be preferable from a social welfare point of view, because it does not reduce the quality of the product available in the two markets but reduces the total investment costs (it is better when the costs are not duplicated). This equilibrium does not militate for strong IPR. From the point of view of global investment partial IPR regime is best.

When $1 < \Delta < \infty$, both countries invest, but country 2 has a less efficient technology. Under all regimes, the investment level of country 2 decreases with Δ (while the investment of country 1 increases). Then, when Δ is large enough, results approach the case given for $\Delta \to \infty$, while when k_2 is small the results are closed to the limit case $\Delta \to 1$. An important issue from a policy perspective is what "large enough" means. The investment levels for two cases are shown in Figure 1. It plots ϕ^F, ϕ^N and ϕ^P as a function of Δ for $\alpha_1 = \alpha_2 = 1$ and $\alpha_1 = 1$, $\alpha_2 = 1/8$.

As Figure 1 illustrates, when country 1 has a much larger demand than country 2 (as in panel b), the level of Δ so that innovation under (P) is larger than under (F) increases.



(a) $k_1 = 2(\alpha_1 + \alpha_2)$, $\alpha_1 = \alpha_2 = 1$ (b) $k_1 = 2(\alpha_1 + \alpha_2)$, $\alpha_1 = 1$, $\alpha_2 = 1/8$

Figure 1: Innovation levels, ϕ^F is in solid line, ϕ^N in dotted, ϕ^P in dashed.

6 Welfare analysis and endogenous IPR regimes

IPR regimes are chosen by governments. They make their decision based on domestic criteria. In this section we focus on the case where country 1 (the advanced economy) has a strong IPR regime. The question we aim to address is whether developing countries, especially fast emerging ones such as China or India, will have an incentive to adopt strong IPR regime, as requested by TRIPS (section 6.1). We assume that country 2 is a follower. It takes the IPR regime of country 1 as given. It will choose the protection regime (F) or (P) which yields the highest national welfare. This in turn will influence the level of welfare in country 1. Finally we analyze how the country 2 IPR regime choice affects the welfare of country 1 (section 6.3). This helps us to compute the total welfare and to check what is the optimal IPR regime from a collective point of view.

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

$$W_i^F = \frac{1}{18}\left[3\alpha_i\Big(2(1+\phi_i^F)^2 + (\phi_i^F - \phi_j^F)^2\Big) + 2\alpha_j(1 + 2\phi_i^F - \phi_j^F)^2\right] - k_i\frac{(\phi_i^F)^2}{2} \tag{40}$$

While under partial protection (P) they are:

$$W_1^P = \frac{1}{72}(27\alpha_1 + 8\alpha_2)(1 + \phi_1^P + \phi_2^P)^2 - k_1\frac{(\phi_1^P)^2}{2} \tag{41}$$

$$W_2^P = \frac{1}{3}\alpha_2(1 + \phi_1^P + \phi_2^P)^2 - k_2\frac{(\phi_2^P)^2}{2} \tag{42}$$

Finally, under no protection (N):

$$W_i^N = \frac{1}{9}(3\alpha_i + \alpha_j)(1 + \phi_1^N + \phi_2^N)^2 - k_i\frac{(\phi_i^N)^2}{2} \tag{43}$$

$$(44)$$

Under Assumption 2, welfare under full protection of IPR (F) can be rewritten as:

$$W_1^F = \frac{\alpha_1 \left(5\gamma(3\Delta-2)^2 + 3\Delta(39\Delta-44)+38\right)}{(15\Delta-8)^2} \tag{45}$$

$$W_2^F = \frac{\alpha_1(\Delta(9\Delta-4)+\gamma(\Delta(81\Delta-76)+18))}{(15\Delta-8)^2} \tag{46}$$

Under partial protection (P):

$$W_1^P = \frac{\alpha_1(1+\gamma)(2\gamma(279+64\gamma)+405)\Delta^2}{(27\Delta+4\gamma(8\Delta-1))^2} \tag{47}$$

$$W_2^P = \frac{16\alpha_1\gamma(1+\gamma)\Delta(27(1+\gamma)\Delta-\gamma)}{(27\Delta+4\gamma(8\Delta-1))^2} \tag{48}$$

Finally, under no protection (N):

$$W_1^N = \frac{2\alpha_1(13+4\gamma)\Delta^2}{(8\Delta-1)^2} \tag{49}$$

$$W_2^N = \frac{\alpha_1\Delta(9\Delta+\gamma(27\Delta-1)-1)}{(8\Delta-1)^2} \tag{50}$$

6.1 Optimal IPR choice of country 2

As mentioned in Section 5.5, when k_1 (and thus k_2) is very large, country 2 is always better off under (F). 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 equations (40) and (42) we deduce 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 this dominance result of (F) over (P) still hold for large enough values of k_1.[5] When k_1 is large, free-riding on country 1 innovation is not worthwhile. Country 2 always chooses the (F) IPR regime to be able to sell its own production in country 1. However this result is upset when k_1 is small. The next result shows that when k_1 is small (under Assumption 2), (P) might yield a higher welfare for country 2 than (F) and thus become an equilibrium.

[5] In fact simulations show that this result holds for a wide range of k_1.

Proposition 3 *Assume that assumption 2 holds. Then there exist two thresholds* $\gamma_1 \simeq 0.2$ *and* $\gamma_2 \simeq 1.14$ *such that:*

- *If* $0 < \gamma < \gamma_1$, $W_2^F > W_2^P$;
- *If* $\gamma_1 \leq \gamma \leq \gamma_2$, *there exists a threshold value* $\tilde{\Delta}(\gamma)$ *such that* $W_2^F \geq W_2^P$ *if and only if* $\Delta \leq \tilde{\Delta}(\gamma)$;
- *If* $\gamma > \gamma_2$, $W_2^F < W_2^P$.

The result of Proposition 3 is illustrated in Figure 2. It shows the welfare levels obtained by country 2 under (F), (P) and (N), plotted as a function of Δ for $k_1 = 2(\alpha_1 + \alpha_2)$ and the cases $\alpha_1 = 1, \alpha_2 = 0.1$ (panel a), $\alpha_1 = 1, \alpha_2 = 0.6$ (panel b) and $\alpha_1 = 1, \alpha_2 = 1.5$ (panel c) respectively.

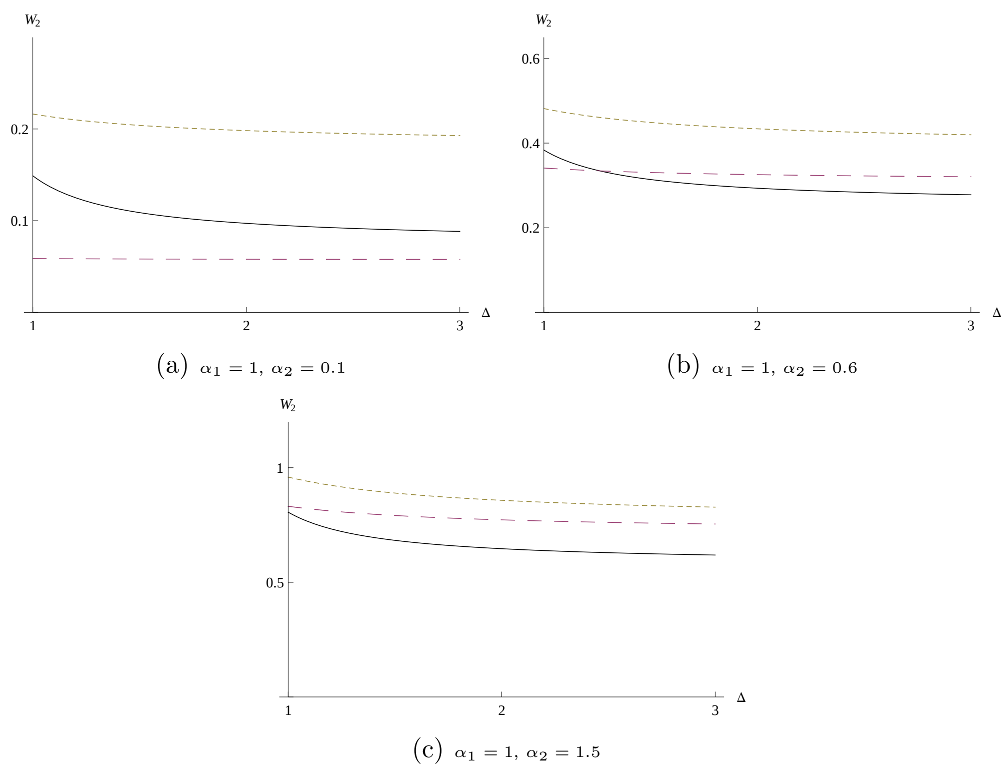


Figure 2: Welfare of country 2 under regime (F) (in solid line), (P) (in dashed line) and (N) (in dotted line).

Country 2 chooses to protect IPR when γ is small (i.e., when the domestic market is relatively small). In this case it is very important for country 2, that wishes to export its production, to have access to the market of country 1. This can happen only if country

2 respects IPR. It thus adopts (F) to be able to trade freely with country 1. By contrast when the size of its national market is large, country 2 can afford not to protect IPR, even if this precludes firm 2 to legally export in country 1. This suggests that fast emerging countries, such as China and India, might become more and more reluctant to enforce IPR as their potentially huge domestic market develop (i.e., as they move from panel a to panel c). This effect might be reinforced by the global economic crisis. As exporting markets shrink for those two countries, they might be tempted to focus more on their internal demand. In this case they will not care about IPR. We thus expect small developing country (i.e., low α_2) being willing to respect IPR and adopt (F), while large emerging countries might be very reluctant to do so and rather stick to (N). This result will be reinforced if illegal imports occur (for instance because it is too costly for country 1 to enforce IPR). Then country 2 would choose to protect IPR even less often. Indeed, can be shown that country 2 always prefers the (N) regime to the (F) regime (see also Figure 2). As argued by proponents of universal IPR regime, this might discourage innovation in country 1. When IPR is not protected in 1 because of illegal imports, the situation is equivalent to regime (N), and total innovation is reduced (investments decease both in 1 and 2). Imperfect enforcement would correspond to an intermediate case between (N) and (F): firm 2 can enter both markets. However, under (P) it cannot free-ride on the innovations developed by 1, while in (N) it does it (thus increasing profits).

6.2 Welfare Analysis

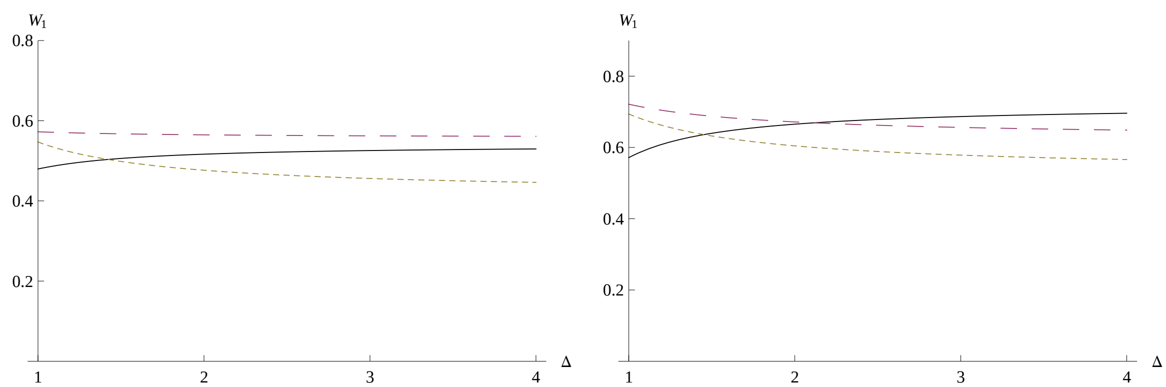
In order to compute the total welfare and thus be able to determine what is the optimal IPR policy from a global point of view we first compute the welfare of country 1. For country 1, it is not clear that the choice of not protecting IPR in country 2 is necessarily a bad thing. If IPR are effectively respected in country 1 by banning illegal imports from country 2, when firm 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 2 increase the stock of innovation offered by 1, increasing in turn the demand for its products and thus its profit.

Proposition 4 *Assume that assumption 2 holds. Then there exist a threshold* $\gamma_1^i \simeq 0.21$ *such that:*

- *If* $\gamma < \gamma_1^i$, $W_1^P > W_1^F$;
- *If* $\gamma \geq \gamma_1^i$, *there exists a threshold value* $\tilde{\Delta}^i(\gamma)$ *such that* $W_1^F \geq W_1^P$ *if and only if* $\Delta \geq \tilde{\Delta}^i(\gamma)$.

Moreover, it can be shown that country 1 prefers (F) to (N) if and only if Δ is higher than a threshold value included in the interval $(1.41, 1.5)$ (and the threshold value increases with γ). This means that, when Δ is small, country 1 could prefer no enforcement of IPR at all.

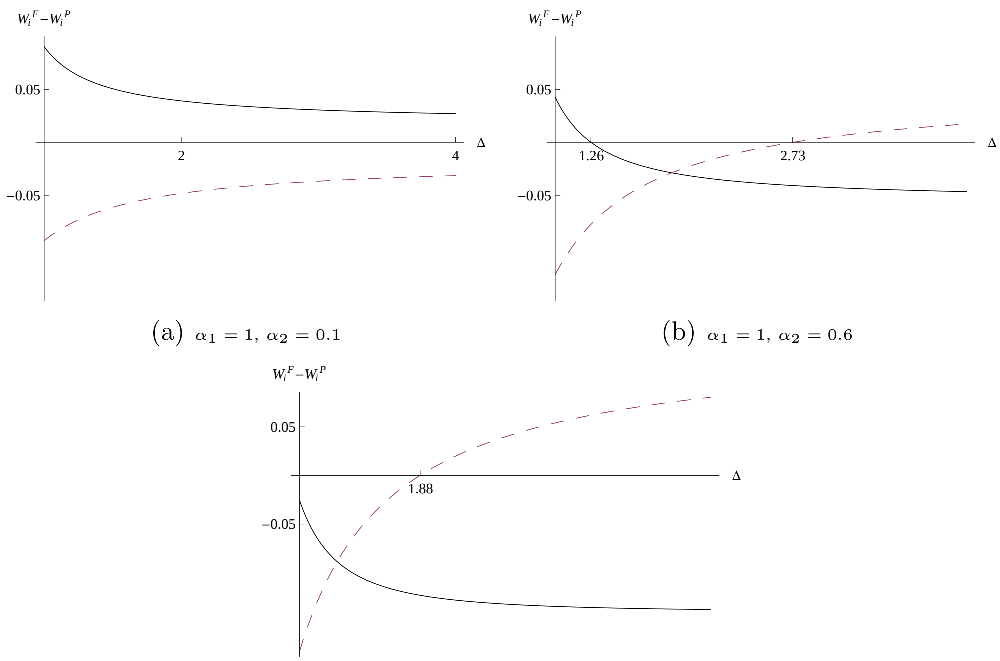
Figure 8 illustrates proposition 4. It show the welfare levels obtained by country 1 under (F), (P) and (N), plotted as a function of Δ for $k_1 = 2(\alpha_1+\alpha_2)$ and $\alpha_1 = 1, \alpha_2 = 0.1$ and $\alpha_1 = 1, \alpha_2 = 1$ respectively.



(a) $\alpha_1 = 1, \alpha_2 = 0.1$ (b) $\alpha_1 = 1,\ \alpha_2 = 1$

Figure 3: Welfare of Country 1, W_1. Regime (F) in solid line, (P) in dashed line and (N) in dotted line.

Comparing the results of Propositions 3 and 4, it is clear that there are potential conflicts of interest between the two countries. For very small levels of α_2 (i.e. when the intensity of demand in country 2 is very small), Country 2 always chooses strong enforcement of IPR (F) while Country 1 would prefer (P). For intermediate values of α_2, a conflict arises for both very small and very high levels of Δ: when country 2 has an efficient R&D technology (small Δ), it chooses regime (F) while country 1 would prefer (P); on the contrary, when country 2 is very inefficient (large Δ), it chooses not to protect IPR (regime P), while country 1 would prefer (F). Finally, when α_2 is large, the conflict arises for Δ large: in this case, country 2 chooses the partial regime (P) to free ride on country 1 technology, while country 1 would prefer full protection of IPR (F). This situation fits well the pharmaceutical industry where countries such as India are producing drugs without respecting IPR. This leads to conflicts and to the lobbying by western pharmaceutical companies to enforce strictly IPR at the world level. Figure 4 illustrates these results, representing the welfare gains obtained by country i when the protection regimes shifts from (P) to (F). In the figure, the difference $W_i^F - W_i^P$ is represented: when this difference is positive, country i prefers (F) to (P). Panel a, b and c represent the case of small, intermediate and large values of α_2 respectively.



(a) $\alpha_1 = 1,\ \alpha_2 = 0.1$

(b) $\alpha_1 = 1,\ \alpha_2 = 0.6$

(c) $\alpha_1 = 1,\ \alpha_2 = 1.5$

Figure 4: Welfare gains $W_i^F - W_i^P$, for Country 2 (in solid line) and Country 1 (in dashed line). When positive, the Country prefers (F) to (P).

We are now ready to study the optimal policy from a collective point of view. One can verify that total welfare under (F) $W_1^F + W_2^F$ hasn't a smooth behavior. For this reason, it is not easy to compare it with the value under (P). However, we can start establishing some local results:

Proposition 5 *Assume that assumption 2 holds. Then there exist three thresholds* $\gamma_1^{ii} \simeq 0.09$*, and* $\gamma_2^{ii} \simeq 0.16$ *and* $\gamma_3^{ii} \simeq 1.5$ *such that:*

- *If* $\Delta \to 1$ *then* $(W_1^F + W_2^F) - (W_1^P + W_2^P) > 0$ *if and only if* $\gamma \leq \gamma_1^{ii}$.
- *If* $\Delta \to \infty$ *then* $(W_1^F + W_2^F) > (W_1^P + W_2^P)$ *if and only if* $\gamma \leq \gamma_2^{ii}$ *or* $\gamma \geq \gamma_3^{ii}$

Proof. The proof is in the appendix. ■

Moreover, it is possible to show that total welfare under (F), $(W_1^F - W_2^F)$, is higher than total welfare under (N), $(W_1^N + W_2^N)$ if and only if Δ is higher than 9.92.

Figure 5 illustrates Proposition 5 for values of γ higher than 0.09. It shows the total welfare levels of country 1 plus country 2 under (F), (P) and (N), plotted as a function of Δ for $\alpha_1 = 1$, $\alpha_2 = 0.2$, $\alpha_1 = \alpha_2 = 1$ and $\alpha_1 = 1, \alpha_2 = 3$.

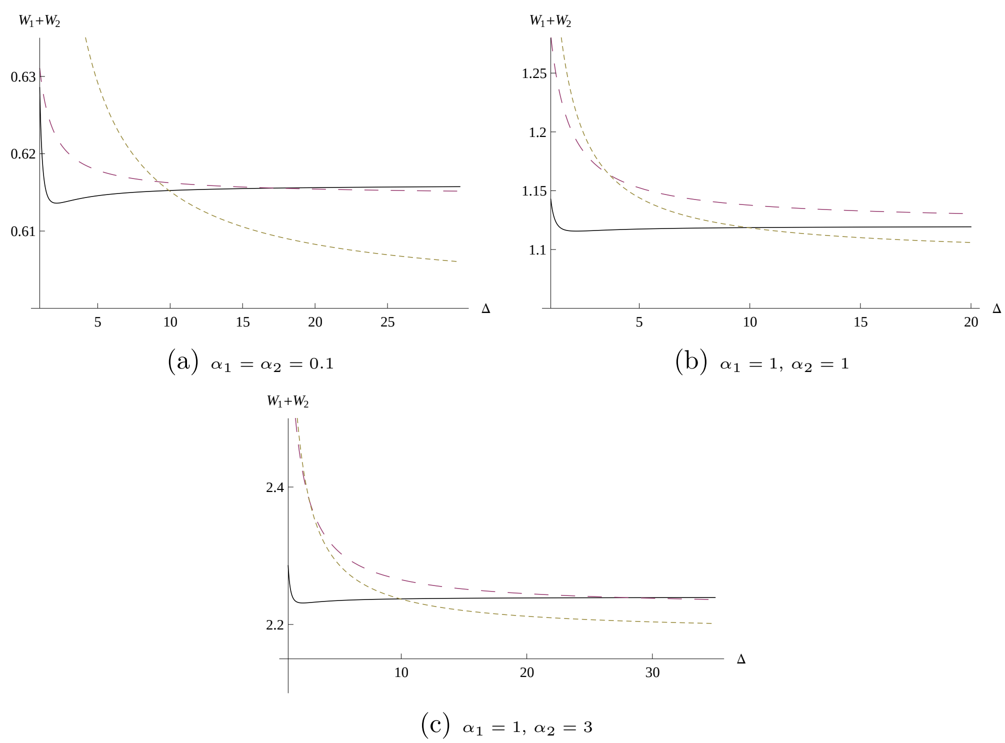


Figure 5: Total Welfare, $W_1 + W_2$. Solid is regime (F), dashed (P) and dotted (N).

From the point of view of total welfare, when country 2 does not do R&D ($\Delta \to \infty$), a strict enforcement of IPR (F) is better at the aggregate level for either very low ($\gamma \leq 0.16$) or high ($\gamma > 1.5$) levels of γ. However, country 2 chooses (F) only if γ is small. Starting from a situation of strong enforcement of IPR in advanced economies, country 2 is not always willing to enforce them. In many cases it will prefer not to protect innovation. Figure 6 better 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 preferred 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) should be preferred from a global point of view. In this case the choice of IPR 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.

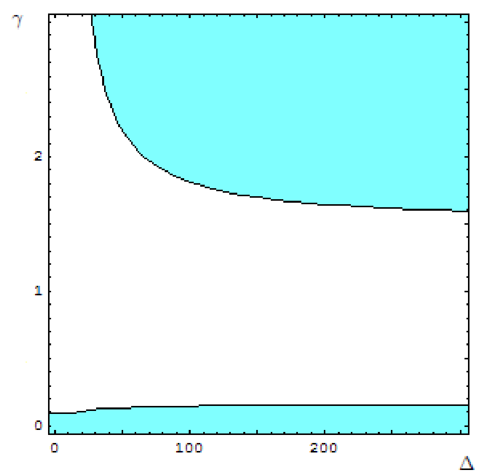


Figure 6: Welfare difference: $(W_1^F + W_2^F) - (W_1^P + W_2^P)$. In the colored region $(W_1^F + W_2^F) - (W_1^P + W_2^P) > 0$.

By contrast when country 2 has developed an efficient R&D system, (i.e., when Δ is very small) welfare is higher under a partial system (P) than under a full system (F), unless α_2 is very small ($\gamma \leq 0.09$). Since developing countries that managed to set up powerful R&D systems are fast emerging countries with very large interior markets, such as India or China, the most relevant case is one of a large α_2. This result suggests that as an emerging country moves from zero investment to substantial investment levels in R&D, partial IPR become more attractive from a global point of view. They are, in this context, more conducive of a high level of investment and of market and demand growth.

6.3 Profits

(very preliminary)

We now study the impact of the protection regime on the profits of the firms. This aspect is likely to be very important in practice, because firms are likely to be able to make pressure on governments in order to favor the preferred protection regime, for instance through lobbying. We first analyze the effect of the different protection regimes on the profit of firm 1. Under assumption 2, we have:

$$\pi_2^F = \frac{\alpha_1(1+\gamma)\Delta(9\Delta-4)}{(15\Delta-8)^2} \tag{51}$$

$$\pi_2^P = \frac{16\alpha_1\gamma(1+\gamma)\Delta(9(1+\gamma)\Delta-\gamma)}{(27\Delta+4\gamma(8\Delta-1))^2} \tag{52}$$

$$\pi_2^N = \frac{\alpha_1(1+\gamma)\Delta(9\Delta-1)}{(8\Delta-1)^2} \tag{53}$$

Proposition 6 *Assume that assumption 2 holds. Then there exist two thresholds* $\gamma_1^{iii} \simeq 0.28$ *and* $\gamma_2^{iii} \simeq 1.36$ *such that:*

- *If* $0 < \gamma < \gamma_1^{iii}$, $\pi_2^F < \pi_2^P$;
- *If* $\gamma_1^{iii} \leq \gamma \leq \gamma_2^{iii}$, *there exists a threshold value* $\tilde{\Delta}^{iii}(\gamma)$ *such that* $\pi_2^F \geq \pi_2^P$ *if and only if* $\Delta \leq \tilde{\Delta}^{iii}(\gamma)$;
- *If* $\gamma > 1.36$, $\pi_2^F < \pi_2^P$.

Proof. The proof is in the appendix. ■

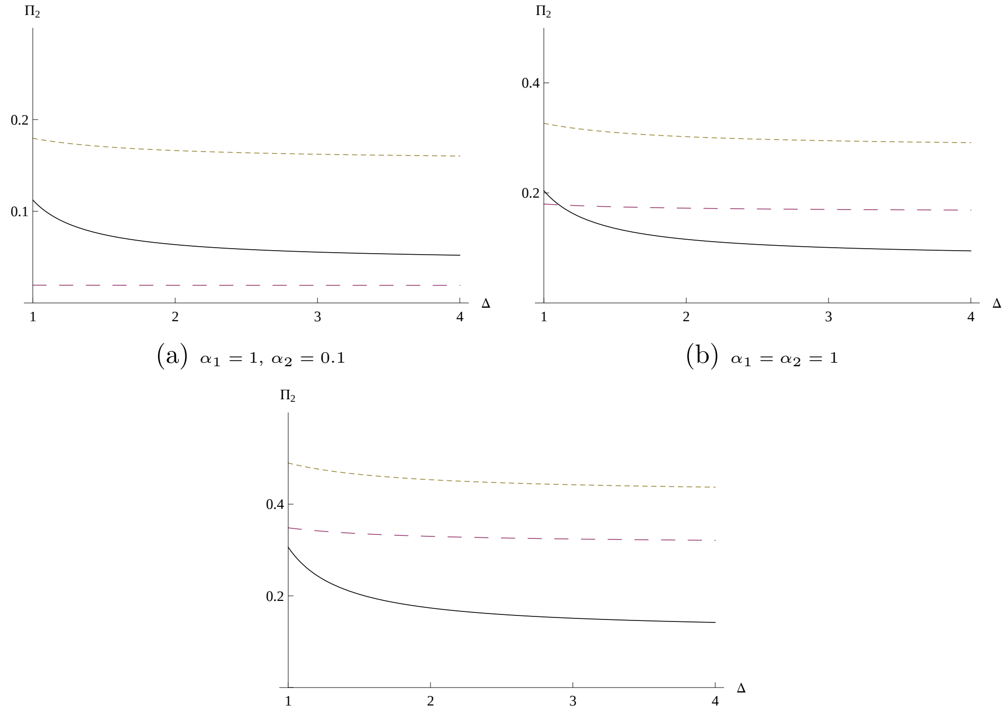
Moreover, one can easily verify that π_2^N is always larger π_2^P.

An interesting question is if this means that on the contrary firm 1 is always penalized by a weaker enforcement of IPR. Indeed, this is not always the case.

$$\pi_1^F = \frac{5\alpha_1(1+\gamma)(3\Delta-2)}{(15\Delta-8)^2} \tag{54}$$

$$\pi_1^P = \frac{\alpha_1(1+\gamma)(9+4\gamma)(27+32\gamma)\Delta^2}{((8\Delta-1)4\gamma+27\delta)^2} \tag{55}$$

$$\pi_1^N = \frac{8\alpha_1(1+\gamma)\Delta^2}{(8\Delta-1)^2} \tag{56}$$



(a) $\alpha_1 = 1, \alpha_2 = 0.1$

(b) $\alpha_1 = \alpha_2 = 1$

(c) $\alpha_1 = 1, \alpha_2 = 2$

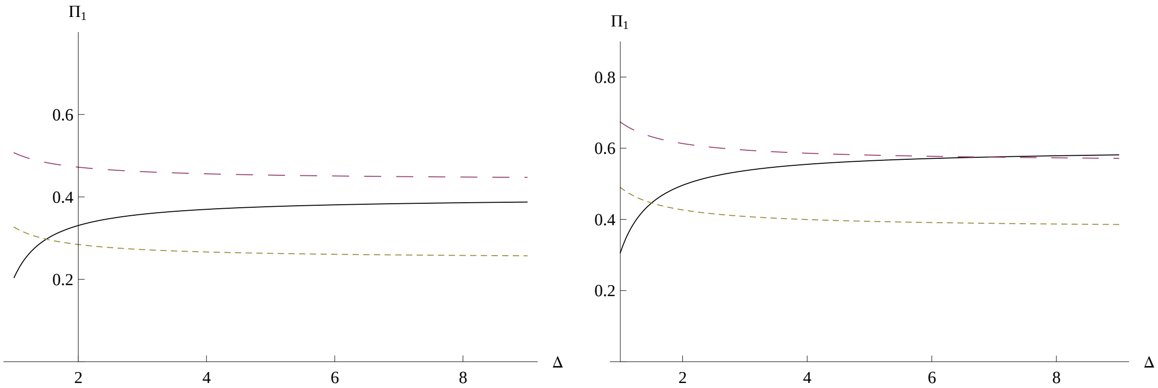
Figure 7: Profit of Firm 2, Π_2. Regime (F) in solid line, (P) in dashed line.

Proposition 7 *Assume that assumption 2 holds. There exists a threshold* $\gamma_1^{iv} = 1.5$ *such that:*

- *If* $\gamma \leq \gamma_1^{iv}$, *there exists a threshold value* $\tilde{\Delta}^{iv}(\gamma)$ *such that* $\pi_1^F \geq \pi_1^P$ *if and only if* $\Delta \geq \tilde{\Delta}^{iv}(\gamma)$*;*
- *If* $\gamma > \gamma_1^{iv}$, $\pi_1^P < \pi_1^F$.

Proof. The proof is in the appendix. ■

It can be easily verified that π_1^P is always larger π_1^N. More interestingly, π_1^N might be larger than π_1^F for low levels of Δ. Indeed, for all γ, π_1^N is larger than π_1^F when $\Delta \leq 1.5$. When the two *R&D* technologies are very similar, both firms invest and free-ride on the investment of the competitor. The (slightly) most efficient firm in this case prefers to be able to replicate the innovations produced by firm 2 instead of having both innovations fully protected.



(a) $\alpha_1 = \alpha_2 = 1$ (b) $\alpha_1 = 1,\ \alpha_2 = 2$

Figure 8: Profit of Firm 2, Π_2. Regime (F) in solid line, (P) in dashed line and (N) in dotted line.

7 Conclusion

This paper has studied in a two countries model the incentives developing countries might have to enforce IPR. It also studied the impact of their adoption choice on global innovation and welfare. The analysis illuminates that one size does not fit all. The results depend both on the maturity of the R&D system and on the size of the developing country internal market. When developing countries do not have a R&D system, the global level of investment in R&D and of welfare are higher under strict and uniform IPR regimes. However with the emergence of new players in the R&D world system, such as China and India, the results are reversed: investment levels in R&D and welfare are higher under a partial IPR.

8 Appendix

Proof of Proposition 2

We already established that $\phi^N \leq \phi^F \leq \phi^*$. We need to check when $\phi^P \leq \phi^F$. Comparing equation (30) with (37) it is straightforward to verify that:

$$
\begin{aligned}
(\phi^F - \phi^P)|_{\Delta \to 1} &= -\frac{9}{7(28\gamma + 27)} \leq 0 \\
(\phi^F - \phi^P)|_{\Delta \to \infty} &= \frac{44\gamma + 9}{160\gamma + 135} \geq 0 \\
\frac{\partial(\phi^F - \phi^P)}{\partial \Delta} &= 12\left(\frac{12\gamma(\gamma+1)}{(27\Delta + 4\gamma(8\Delta - 1))^2} + \frac{1}{(15\Delta - 8)^2}\right) \geq 0
\end{aligned}
$$

We deduce that the difference $\phi^F - \phi^P)$ is always increasing in Δ. Moreover, at the lowest admissible value $\Delta \to 1$, the difference is negative. At the other extreme $\Delta \to \infty$ is positive. Then, there exists a positive threshold $\hat{\Delta}(\gamma)$ such that $\phi^F - \phi^P) \geq 0$ if and only if $\Delta \geq \hat{\Delta}(\gamma)$. This threshold corresponds to:

$$
\hat{\Delta}(\gamma) = \frac{2\left(15\gamma + \sqrt{\gamma(49\gamma + 54) + 9} + 3\right)}{44\gamma + 9}
$$

which is decreasing in γ for all positive values of γ.

Proof of Proposition 3

Comparing equation (46) with (48) it is straightforward to verify that:

$$
\begin{aligned}
(W_2^F - W_2^P)|_{\Delta \to 1} &= -\frac{3\alpha_1(\gamma(56\gamma(14\gamma + 17) - 1053) - 1215)}{49(28\gamma + 27)^2} \\
(W_2^F - W_2^P)|_{\Delta \to \infty} &= -\frac{\alpha_1(\gamma(16\gamma(99\gamma + 314) + 2511) - 729)}{25(32\gamma + 27)^2} \\
\frac{\partial(W_2^F - W_2^P)}{\partial \Delta} &= \frac{4}{5}\alpha_1\left(\gamma\left(\frac{85 - 195\Delta}{(15\Delta - 8)^3} + \frac{20\gamma(\gamma+1)(189\Delta + 4\gamma(46\Delta - 1))}{(27\Delta + 4\gamma(8\Delta - 1))^3}\right) - \frac{5(21\Delta - 8)}{(15\Delta - 8)^3}\right) \\
\frac{\partial(W_2^F - W_2^P)}{\partial \Delta} &= \frac{4}{5}\alpha\left(-3\left(\frac{195\Delta - 85}{(15\Delta - 8)^3} + \frac{240(189\Delta + 12(46\Delta - 1))}{(27\Delta + 12(8\Delta - 1))^3}\right) - \frac{5(21\Delta - 8)}{(15\Delta - 8)^3}\right)
\end{aligned}
$$

Then, the difference $W_2^F - W_2^P$ is decreasing in Δ at least for γ sufficiently small (and $\gamma \leq 1.14$ is a sufficient condition). At the lowest admissible value $\Delta \to 1$, the difference is positive if and only if $\gamma \geq 1.14$. At the other extreme $\Delta \to \infty$ is positive if and only if $\gamma \geq 0.2$. Then, for $\gamma < 0.2$ $W_2^F - W_2^P)$ is always positive. In fact, this holds both at $\Delta \to 1$ and $\Delta \to \infty$ and the difference $W_2^F - W_2^P)$ is decreasing. For $0.2 \leq \gamma \leq 1.14$, $W_2^F - W_2^P)$ is positive in $\Delta \to 1$ and negative in $\Delta \to \infty$. Since $W_2^F - W_2^P$ is always increasing, there must exist a threshold value $\tilde{\Delta}(\gamma)$ such that $W_2^F \geq W_2^P$ if and only if $\Delta \leq \tilde{\Delta}(\gamma)$. Finally, if $\gamma > 1.14$ $W_2^F - W_2^P)$ is always negative.

Proof of Proposition 4

Comparing equation (45) with (47) it is straightforward to verify that:

$$
\begin{aligned}
(W_1^F - W_1^P)|_{\Delta\to 1} &= -\frac{6\alpha_1(\gamma(7\gamma(56\gamma + 191) + 1461) + 513)}{49(28\gamma + 27)^2} \\
(W_1^F - W_1^P)|_{\Delta\to \infty} &= \frac{2\alpha_1(\gamma(\gamma(960\gamma + 2401) + 1017) - 324)}{25(32\gamma + 27)^2} \\
\frac{\partial(W_1^F - W_1^P)}{\partial\Delta} &= \frac{4}{5}\alpha_1\left(\frac{15(9\Delta - 7)}{(15\Delta - 8)^3} + 5\gamma\left(\frac{2(\gamma + 1)(2\gamma(64\gamma + 279) + 405)\Delta}{(27\Delta + 4\gamma(8\Delta - 1))^3} + \frac{15(3\Delta - 2)}{(15\Delta - 8)^3}\right)\right)
\end{aligned}
$$

We deduce that the difference $\phi^F - \phi^P)$ is increasing in Δ. Moreover, at the lowest admissible value $\Delta \to 1$, the difference is negative. At the other extreme $\Delta \to \infty$ is positive if and only if $\gamma \geq 0.21$. Then, for $\gamma < 0.21$ $W_2^F - W_2^P)$ must be always positive. For $\gamma > 0.2$, $W_2^F - W_2^P)$ is negative in $\Delta \to 1$ and positive in $\Delta \to \infty$. Since $W_1^F - W_1^P$ is always increasing, this means that there must exist a threshold value $\tilde{\Delta}^i(\gamma)$ such that $W_1^F \geq W_1^P$ if and only if $\tilde{\Delta}^i(\gamma)$.

Proof of Proposition 5

Using equations (45), (47), (46) and (48) one can verify that:

$$
\begin{aligned}
(W_1^F + W_2^F) - (W_1^P + W_2^P)|_{\Delta\to 1} &= -\frac{3\alpha_1(\gamma + 1)(14\gamma(16\gamma + 21) - 27)}{7(28\gamma + 27)^2} \\
(W_1^F + W_2^F) - (W_1^P + W_2^P)|_{\Delta\to \infty} &= \frac{3\alpha(\gamma + 1)(2\gamma - 3)(56\gamma - 9)}{25(32\gamma + 27)^2}
\end{aligned}
$$

Then, at the lowest admissible value $\Delta \to 1$, the difference is positive if and only if $\gamma \leq 0.09$. At the other extreme $\Delta \to \infty$ is positive if and only if $\gamma \geq 1.5$ or $\gamma \leq 0.16$. Plotting the contour of the difference $(W_1^F + W_2^F) - (W_1^P + W_2^P)$ at $(W_1^F + W_2^F) - (W_1^P + W_2^P) = 0$, we obtain the result in Figure 6.

Proof of Proposition 6

Comparing equation (51) with (52), it is straightforward to verify that:

$$
\begin{aligned}
(\pi_2^F - \pi_2^P)|_{\Delta\to 1} &= -\frac{3\alpha_1(\gamma+1)\left(784\gamma^2-168\gamma-1215\right)}{49(28\gamma+27)^2} \\
(\pi_2^F - \pi_2^P)|_{\Delta\to \infty} &= -\frac{\alpha_1(\gamma+1)\left(2576\gamma^2+1872\gamma-729\right)}{25(32\gamma+27)^2} \\
\frac{\partial(\pi_2^F - \pi_2^P)}{\partial\Delta} &= \frac{4}{5}\alpha_1(\gamma+1)\left(-\frac{5(21\Delta-8)+\frac{20\gamma^2(5(8\gamma+9)\Delta-4\gamma)}{(27\Delta+4\gamma(8\Delta-1))^3}}{(15\Delta-8)^3}\right) \le 0
\end{aligned}
$$

We deduce that 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 $\gamma \geq 0.28$. At the other extreme $\Delta \to \infty$ is positive if and only if $\gamma \geq 1.36$. Then, for $\gamma < 0.28$ $\pi_2^F - \pi_2^P$ is always positive. For $0.28 \leq \gamma \leq 1.36$, $\pi_2^F - \pi_2^P$ is positive in $\Delta \to 1$ and negative in $\Delta \to \infty$. Since $\pi_2^F - \pi_2^P$ is always increasing, there must exist a threshold value $\tilde{\Delta}^{iii}(\gamma)$ such that $\pi_2^F - \pi_2^P$ if and only if $\Delta \leq \tilde{\Delta}^{iii}(\gamma)$. Finally, if $\gamma > 1.36$ $\pi_2^F - \pi_2^P$ is always negative.

Moreover, from equations (51) and (53) one can easily verify that the difference $\pi_2^F - \pi_2^N$ is always negative.

Proof of Proposition 7

Comparing equation (54) with (55), it is straightforward to verify that:

$$
\begin{aligned}
(\pi_1^F - \pi_1^P)|_{\Delta\to 1} &= -\frac{3\alpha_1(\gamma+1)\left(784\gamma^2-168\gamma-1215\right)}{49(28\gamma+27)^2} \le 0 \\
(\pi_1^F - \pi_1^P)|_{\Delta\to \infty} &= -\frac{\alpha_1(\gamma+1)\left(2576\gamma^2+1872\gamma-729\right)}{25(32\gamma+27)^2} \\
\frac{\partial(\pi_1^F - \pi_1^P)}{\partial\Delta} &= \frac{4}{5}\alpha_1(\gamma+1)\left(\frac{20\gamma^2(5(8\gamma+9)\Delta-4\gamma)}{(27\Delta+4\gamma(8\Delta-1))^3}-\frac{5(21\Delta-8)}{(15\Delta-8)^3}\right) \ge 0
\end{aligned}
$$

We deduce that the difference $\pi_1^F - \pi_1^P$ is increasing in Δ. Moreover, at the lowest admissible value $\Delta \to 1$, the difference is always negative. At the other extreme $\Delta \to \infty$ is positive if and only if $\gamma \geq \frac{3}{2}$. Then, for $\gamma < \frac{3}{2}$ $\pi_1^F - \pi_1^P$ is always negative. For $\gamma \geq \frac{3}{2}$, $\pi_1^F - \pi_1^P$ is positive in $\Delta \to 1$ and negative in $\Delta \to \infty$. Since $\pi_1^F - \pi_1^P$ is always increasing, this means that there must exist a threshold value $\tilde{\Delta}^{iv}(\gamma)$ such that $\pi_1^F - \pi_1^P$ if and only if $\Delta \leq \tilde{\Delta}^{iv}(\gamma)$.

Moreover, from equations (54) and (56) one can easily verify that the difference $\pi_1^F - \pi_1^N$ is positive if and only if $\Delta \geq 1.5$.

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