Intellectual Property Rights Protection in Developing Countries

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Abstract

This paper studies the incentives that developing countries have to protect 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 others 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 and innovation are 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. After presenting the theoretical framework, the paper offers an empirical analysis of the testable predictions of the model.

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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 former 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 (e.g., see Sachs 2002)

The economic literature on the impact of IPR is 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 and illegal imports are banned. In the case of illegal 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 the more protection of IPR the better, 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, 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 firms 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. This suggests that fast emerging countries, might become more and more reluctant to enforce IPR as their potentially huge domestic market develop. On the other hand, an increase of foreign market access (which increases the relative importance of the size of foreign demand) should reduce this reluctance, as IPR protection enhance (legal) export opportunities.

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 the firm in the poor country increase the stock of innovation offered by the 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 is thus challenging.

Regarding global welfare, when the poor country has a very inefficient R&D technology, global welfare is shown to be non-monotone with respect to the relative size of the developing market. In fact, when the internal market of the poor country is very small, this country prefers to protect IPR and this choice turns out to be globally efficient, also increasing welfare in the developed country. On the contrary, when the internal market of the developing country grows, this country will choose partial protection, harming the developed country. When the size of the developing market becomes very large, the losses inflicted to the developed country are higher than the gain obtained: partial protection is chosen but this reduces global welfare. These results are modified when the emerging country moves from zero investment to substantial investment levels in R&D. In this case, 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.

Our analysis has two main empirically testable predictions. The first is that the incentives to IPR protection in developing countries are decreasing in the size of the market (which is in turn related to economic development, as measured by an increase of per-capita GDP). Then, we should observe a U shaped relationship between IPR enforcement and the size of internal demand. Second, global innovation and in particular innovation in developing countries does not always increases with IPR protection. Both predictions are confirmed in the empirical analysis.

The rest of the paper is structured as follows. Section 2 reviews the related literature on IPR. Section 3 develops the model. The open economy is studied in section 4, which derives equilibrium investment levels under different regimes of IPR: none, partial, and full. The welfare analysis is conducted in section 5. Section 6.1 presents the data. Section 6.2 develops the empirical analysis. Finally section 7 concludes.

2 Related Literature

2.1 Theoretical literature

Starting with the seminal paper of Grossman and Lai (2004), several papers have considered the intellectual property protection in a context of horizontal innovation. These papers generally assume that innovation generates an increase in variety in an economy in which consumers are characterized by Dixit-Stiglitz preferences. In all cases patents induce a static inefficiency due to monopoly pricing. Grossman and Lai (2004) looks at two 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, focuses on vertical innovation: innovation increases the quality of a product (and not the number of products). Then, in our analysis we do not look at innovation as a process which increases diversification, but as an improvement in the quality of the produced goods (a new and more effective drug, a new generation of mobile phones, ...). Also in this case, the classical results concerning the tension between market power distortions (monopoly power granted by patents) and innovation incentives are at stake. 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.

A distinct stream of literature, which we see as complementary to our contribution, study the impact of parallel imports (PI) on innovation. In the presence of parallel imports (or international exhaustion) the possibility to perform price discrimination is reduced. This may in turn weaken the incentives 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 OU with a high wholesale price. If so, banning such trade would raise expected welfare.

Although we do not look to parallel imports, we consider the impact of imitation (and illegal sales of imitated goods). As for parallel imports, this increases product market competition and affect innovation incentives. For instance, we also identify the level of innovation obtained in the limit 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 as in the case of PI, 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. For more specific issues concerning PI, we refer to the cited literature.

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, for which the market power distortion does not arise). 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 do not look at philanthropic provision of free innovation, but we concentrate on imitation (which also has the effect of diffusing innovation for free, but without the authorization of the providers). Alos in our case, competition from imitators "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).

2.2 Empirical literature

Our theoretical model predicts that least developed countries with small markets would be willing to protect IPR. By contrast, when the size of the national market increases, developing countries optimally choose not to protect IPR. These findings would imply a U-shape relationship between development and IPR enforcement. This finding is compatible with the results of other empirical works. The first to identify an empirical U-shape relationship between the level of development and patent protection were Maskus (2000) and Braga, Fink, and Sepulveda (2000). In their analysis, IPRs are found to be U-shaped with respect to per-capita income. Following these contributions, Chen and Puttitanun (2005) made the first attempt to couple theoretical and empirical findings. They propose a theoretical model with two sectors, the import and the domestic sectors. In each sector, the non-innovating firms can imitate the innovations developed by competitors, with an imitative ability which depends both on the technological/development level of the country (measured by per-capita GDP) and on the level of enforcement of IPR. In this framework, Chen and Puttitanun (2005) show a trade-off between imitating the foreign technology (which increases the domestic quality and thus competition) and stimulating domestic innovation. In their work, the level of innovation in the developed countries is considered as fixed and firms in the developing country produce only for local consumers (no export). For some values of the parameters their simple model can deliver the prediction that, when the level of development of the country increases, the level of protection first decreases and then increases. These results are empirically tested and a U-shaped is founded in the data. Our model generalizes their analysis providing new theoretical foundations to the behavior of IPR enforcement. First, we take into account the investment incentives of the firm of the developed country and their sensitivity to the choice of IPR in the developed one. Moreover, we also allow the developing country to export. Our analysis distinguishes among the income level, the size (population) of the country and its technological development. As our model shows, the size of demand plays a crucial role in determining the willingness to enforce IPR. The level of enforcement is shown to be a U-shaped function of the relative size of domestic demand.

Concerning the impact of IPR enforcement on innovation, as in Chen and Puttitanun (2005), when the developing country does not respect IPR, this increases competition in the domestic market and decreases domestic expenditure in R&D. However, this does not imply that the total level of innovation decreases, for two reasons. First, innovation is incremental and imitation avoids investment cost duplications. Second, the level of innovation of the firms in the developing country also respond to a change in IPR enforcement in the developing region. Then our model predicts that an increase in IPR enforcement unambiguously decreases the relative quality of the goods produced in the developing country. On the other hand, total innovation can increase or decrease. In this sense, our paper contributes to the understanding on the forces that can encourage as opposed to discourage innovation, and the empirical analysis adds on this issue by identifying the most relevant in practice.

More generally our paper relates to the empirical literature on the effects of an increase in patent protection on innovation in particular sectors, such as the pharmaceutical industry. In this context, some recent studies have considered the impact of TRIPS and their IPR requirements on innovation in the pharmaceutical industry. Qian (2007) evaluates the effects of patent protection on pharmaceutical innovations for 26 countries that established pharmaceutical patent laws during 1978-2002. The study shows that national patent protection alone does not stimulate domestic innovation (measured by changes in citation-weighted U.S. patent awards, domestic R&D, and pharmaceutical industry exports). However, domestic innovation accelerates in countries with higher levels of economic development, educational attainment, and economic freedom. Kyle and McGahan (Forthcoming) tests the hypothesis that, as a consequence of TRIPS, increased patent protection results in greater drug development effort. They find that patent protection in high income countries is associated with increases in R&D effort but the introduction of patents in developing countries has not been followed by greater R&D investment in the diseases that are most prevalent there. Our paper provides a first theoretical explanation of the different impact of IPR protection in developing and developed countries, allowing for partial enforcement of IPR and stressing the role of market size and technical development. In addition, we test our results taking into account on-the-frontier and inside-the-frontier innovation on the manufacturing sectors of a wide panel of countries. Our analysis shows that full (uniform) IPR protection, as opposed to partial protection, can be detrimental to both imitation-driven innovation and on-the-frontier innovation in the developing countries (as measured by patent activity).

Our paper also relates to another stream of empirical literature which concentrates on the relationship between IPR protection and trade. These works starts identifying a basic trade-off between the enhanced market power of the innovating firm created by stronger patents (market power effect) and the larger effective market size generated by the reduced abilities of local firms to imitate the product (market expansion). The market power effect would generally induce the firm to export less of its patentable product to the market with the stronger IPRs. On the contrary, the market expansion effect would increase the demand of the patented good. Maskus and Penubarti (1995) find some evidence of the prevailing of the market expansion effect, showing that an increase in patent protection has a positive impact on bilateral manufacturing imports from OECD countries into both small and large developing economies. They also show that this effect is larger in larger markets. Similarly, Smith (1999) assesses how US exports are sensible to national differences in IPR. The main result of this literature is that stronger IPR have a market expansion effect in countries with a strong capacity of imitation.[1]. In our model with the exception of Extension 2 (imperfect imitation), we assume perfect imitation ability. Under this assumption, increasing patent protection in the developing country generally increases the quantity imported from the developed one. The reason is simply that when IPR are enforced in the developing country, imitation is banned and the relative quality of the good produced in the developing country decreases, increasing the market share of the imported good. On the other hand, when imitation is only partial

[1]A possible problem of this approach is that the variables used to measure imitation potential (usually the number of R&D scientists, engineers and technicians, the educational attainment and R&D expenditure) could also be capturing technological development and thus autonomous innovation ability

as in Extension 2 (i.e. the imitation ability in the developing country is lower), the level of innovation in the developed country increases as well as the quantity exported to the developing one. Then, a reduced imitation ability decreases the impact of stronger IPR on imports in our model. This finding is clearly confirmed by the existing empirical literature, to which we refer for further details.

3 The model

We consider a two countries economy. There is a firm producing a vertically differentiated commodity in each country. We focus on quality augmented linear demand.[2] Demand for good i in country j writes:

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

where $a_j > 0$ and $b_j > 0$ are the exogenous linear demand parameters, v_i represents the quality of good i, and q_{ij} is the quantity of good i sold in country j. It is easy to check that $p_{1j} - p_{2j} = (v_1 - v_2)a_j$ so that, unless goods have the same quality, they are not perfect substitutes. To be more specific, the price of commodity i increases with its quality and with the price of its competitor, it decreases with the quality of its competitor.

Countries differ in population size and per-capita income, which are relevant demand characteristics. In the empirical application, a_j is interpreted as the per-capita income and b_j as the *inverse* of the population size of country j.[3] 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). We are able to capture the heterogeneity of both

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

[3] To see this point assume that the indirect utility of a representative consumer consuming two goods of quality v_1 and v_2 is given by: $V(w, q_1, q_2) = u(w) + v_1 q_1 + v_2 q_2 - \frac{(q_1+q_2)^2}{2}$ where q_i is the quantity of good $i = 1, 2$, u is an increasing and concave function of the consumer net income $w = R - p_1 q_1 - p_2 q_2$. Optimizing V with respect to q_i yields: $\frac{\partial V}{\partial q_i} = -p_i u' + v_i - (q_1 + q_2)$ $(i = 1, 2)$. We deduce that if $v_i - p_i u' > v_j - p_j u'$ then $q_j = 0$ and $q_i = v_i - p_i u'$. On the other hand, if $\frac{1}{u'} v_i - p_i = \frac{1}{u'} v_j - p_j$ the demand of a representative consumer can be written as $q_1 + q_2 = v_i - \frac{p_i}{u'}$. If N is the size of the population the total demand is $Q_1 + Q_2 = N v_i - N u' p_i$. Let $b \equiv \frac{1}{N}$ be the inverse of the population size, and $a \equiv \frac{1}{u'}$ be the inverse of the marginal utility of income, which corresponds to the per capita income if the utility of income is logarithmic, $u(y) = log(y)$. The aggregated inverse demand is $P_i = a\big(v_i - b(Q_1 + Q_2)\big)$. With 2 countries, the price of good i in country j becomes p_{ij}, and the total quantity in country j, $q_{1j} + q_{2j}$, yielding (1).

advanced and developing countries. The parameter $\alpha_i = a_i/b_i$ is proportional to the GDP of the country, and it reflects the intensity of the demand in country i; $\alpha = \alpha_1 + \alpha_2$ is the depth of the integrated market. A parameter which plays an important role in the analysis below is the ratio

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

The ratio γ captures the relative intensity of demand in country 2. A small γ indicates that the developing country market is small compared to the internal market of the advanced economy. It corresponds to traditional north-south trade relation, where the developing country GDP and internal market are small. A large γ indicates that the foreign market is important for the advanced economy. It corresponds to the new case of trade relations between fast emerging countries such as China, India or Brazil, and advanced economies.

Regarding production we set the common level of quality before investment to 1.[4] We assume that innovation increases the quality of the commodity by ϕ_i. This corresponds to a quality enhancing innovation, where an increase in the quality shifts the linear demand upwards, as in Sutton (1991, 1997). This may represent for instance the introduction of a new generation of mobile phone. 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 $i = 1, 2$. That is, a larger k_i corresponds to a less efficient R&D process. Without any loss of generality we assume that country 1 has the most efficient $R\&D$ process (i.e., it is the rich country). We set $k_1 = k$ and $k_2 = \Delta k$ with

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

The ratio $\Delta \geq 1$ plays an important role in the analysis below. It is with $\gamma > 0$ the other static comparative parameter of the paper. By investing $k_i \frac{\phi_i^2}{2}$ a firm increases the quality of the good from $v_i = 1$ to $v_i = 1 + \phi_i$. Innovation is thus deterministic.[5] Finally once a quality is developed, the marginal costs of production are normalized to zero for both firms.[6]

[4]In appendix 9.5 we relax this assumption. The main effect of introducing different initial levels of quality is to reduce the incentive that the developing country has to enforce IPR.

[5]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.

[6]Alternatively, we could define p_i as the price net of marginal cost of firm i. In this case, an increase in

4 Investment in R&D

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). In the first stage they might choose to copy their competitor innovation, or not. For the simplicity of the exposition, we assume that if imitation occurs it is perfect. However our results are robust to the assumption of imperfect imitation (see Appendix 9.3). Because of this potential free-rider problem, the level of protection of the innovation influences investment in R&D. We distinguish three intellectual property rights (IPR) regimes, denoted $r = F, N, P$:

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

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

3. Partial protection (P): only country 1 (i.e., the rich country) protects innovation. If firm 2 violates the patent rights of firm 1, it will not be able to sell its product in country 1. Moreover, since country 2 does not enforce IPR, firm 1 can reproduce the incremental technological improvement developed by firm 2, if any, so that $v_i^P = v_i^N = 1 + \phi_i + \phi_j$.

If both countries enforce IPR (regime F), imitation is not allowed and each firm privately exploits the benefits of its R&D activity. If one or both countries do not enforce IPRs (regime N or P), imitation occurs in *both* countries. In the case of imitation, innovations are assumed to be cumulative, each firm can imitate the rival and additionally improve the quality through its own innovation activity. This assumption is realistic in many industries. However, in appendix 9.4 we consider the alternative hypothesis that under imitation (regimes P and N), the quality of the good corresponds to the maximum quality (i.e. $v_i^N = v_i^P = 1 + \max\{\phi_i, \phi_j\}$). It turns out that this case is equivalent to the the limit case $\Delta \to \infty$ discussed in the paper.[7]

the intercept parameter $a_i v_i$, for the same level of income a_i could be both interpreted as an increase in quality v_i or a decrease in the marginal production cost. This alternative model gives similar qualitative results (computations available upon request).

[7]A shown in Section 9.4 when $v_i^N = v_i^P = 1+\max\{\phi_i, \phi_j\}$, there always exist an equilibrium in which only firm 1 invests, which is also the equilibrium when $k_2 \to \infty$. Moreover this equilibrium is unique

Differences between N and P arise after the investment phase: Each country becomes a duopoly except in the partial regime (P) where the country 1, which enforces strictly IPR, forbids importation by the imitator, and is thus a monopoly.[8] To keep the exposition simple we assume that exporting entails no transportation cost. Appendix 9.1 shows that our main results are robust to the introduction of a transportation cost.

The problem is solved backward by first computing the quantities offered by the firms in the different regimes. In regime $r = F, N$ and in regime $r = P$ for country 2 firms 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 defined equation (1) with respect to quality v_i^r. The cost of R&D is in bracket 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 (FOC) are sufficient. At the second stage of the production game, the quantity produced by firm i for country j is the Cournot quantity: $q_{ij}^r = \frac{2v_i^r - v_{-i}^r}{3b_j}$, where the index $-i \neq i$ represents the competitor and the value of v_i^r depends on the IPR regime, i.e. $v_i^r \in \{v_i^F, v_i^N, v_i^P\}$. Under the partial protection regime (P) the quantities produced in country 1 are the monopoly quantity of firm 1. That is, $q_{21}^P = 0$ and $q_{11}^P = q_1^M(v_1^P) = \frac{v_1^P}{2b_1}$. We deduce that the quantities produced at the second stage of the game are:

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

The profit of firm $i = 1, 2$ then writes:

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

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

4.1 Socially optimal level of investment

As a benchmark case we first compute the optimal level of innovation taking into account the firms market power (i.e., property rights). That is, we compute the optimal investment level from a global social point of view when the production levels are defined by

when γ is not too large and Δ is not too small (i.e. larger than 1), which correspond to the case where country 2 is the developing one.

[8]We check the robustness of the results to the possibility of illegal imports in appendix 9.2.

(4). The welfare of country $j = 1, 2$ is $W_j^r = S_j^r + \Pi_j^r$ where Π_j^r is defined equation (5) and

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

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

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

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

Assumption 1 $\qquad k = 2\alpha$

Since we are interested in the role of IPR on innovation activities, we concentrate on relatively small k (i.e., close to the threshold value $\frac{16}{9}\alpha$), for which innovation matters and piracy with regime P can be an equilibrium.[10]

Under the assumption A1 the optimal level of investment, $\phi^* = \phi_1^* + \phi_2^*$, is:

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

[9]Since $\frac{8}{9}\frac{1+\Delta}{\Delta}\alpha$ is decreasing in $\Delta \geq 1$, the maximum value is obtained for $\Delta = 1$.

[10]By contrast when k (and thus $k_2 = \Delta k \geq k$) are very large compared to α, country 2 is always better off under (F) (see section 5.1). Indeed, when R&D is very costly only marginal innovations can take place. Innovation does not matter and the regimes (F) and (P) mainly differ in the possibility of selling output in one or two markets. This is a case where country 2 always chooses the full IPR regime to be able to export its production in country 1.

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

The appendix 9.1 extends the analysis to the case with a linear transportation cost.[11] When transportation costs are positive, the size of the two markets in terms of population matters. In particular, the lower is b_1 or b_2, the higher is the investment. Moreover, a decrease in transportation costs always increases investment, and this effect is larger when the populations of the two countries increase.

4.2 Full IPR protection (F regime)

In the case of full IPR protection, the quality of good i after investment is determined by $\phi_i^F = \phi_i$. Indeed under the F regime firms cannot free-ride on each other innovation. Investment costs need to be duplicated to obtain similar level of quality in both firms. At the second stage quantities are given by the levels in (4). At the first stage (investment stage), firm i maximizes the profit (5) with respect to ϕ_i, for a given level of ϕ_j, $i \neq j$. Profit maximization gives the following reaction function:

$$\phi_i(\phi_j) = \frac{\alpha}{2.25k_i - 2\alpha}(1 - \phi_j) \tag{9}$$

The slope of the reaction function is negative: $\frac{\partial \phi_i(\phi_j)}{\partial \phi_j} = \frac{-\alpha}{2.25k_i - 2\alpha} < 0$ under assumption 1. 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 so firm j's incentive 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.[12] Solving the system of first order conditions, we obtain that $\phi_i^F = \frac{3\frac{k_j}{\alpha} - 4}{15\Delta - 8}$.

The level of quality chosen by firm i depends positively on k_j, the parameter describing the competitor's cost of innovation. Since by convention $k_2 = \Delta k \geq k_1 = k$, the highest quality available to consumers in this setting is $\phi^F = \phi_1^F$, which after some rewritings is

[11] With linear transportation cost, t, the formula becomes $\phi_t^* = \frac{4(\Delta+1)}{5\Delta-4}(1 - \frac{t}{\alpha}\frac{b_1+b_2}{2b_1b_2})$ (see appendix 9.1).

[12] 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).

under A1:

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

Term ϕ^F is an increasing function of $\Delta \geq 1$. Not surprisingly, when the relative efficiency of firm 1 increases, its incentives to invest also increase. This is related to the fact that the investment levels of the two firms are strategic substitutes.

As shown in the appendix 9.1, when transportation costs are positive, the relative size of the internal market also 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.[13] 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, a decrease in transportation costs tends to increase the negative impact of competition on domestic profits, and thus to reduce the level of investment.

4.3 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 $1 + \phi^N = 1 + \phi_1^N + \phi_2^N$. At the second stage quantities are given by the Cournot levels in (4). At the first stage, profit maximization gives firm $i = 1, 2$ reaction function:

$$\phi_i(\phi_j) = \frac{\alpha}{\frac{9}{2}k_i - \alpha}(1 + \phi_j) \tag{11}$$

In this case the slope of the reaction function is positive: $\frac{\partial \phi_i(\phi_j)}{\partial \phi_j} = \frac{\alpha}{\frac{9}{2}k_i - \alpha} > 0$ under A1. Quality levels (and thus investment) are *strategic complements*. This result is counter-intuitive because free-riding behaviors are associated to 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 the firms can free ride on each other.

[13] Interestingly, the same effect does not occur when per-capita revenue increases. Starting from a symmetric situation ($a_i = a_j$), if the revenue of a country increases, both firms invest more, but the investment levels 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.

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 loosing the benefit of its own innovation, to win market shares it tends to invest more when its competitor invests more. Solving for the equilibrium we have: $\phi_i^N = \frac{1}{8\Delta-1}\frac{k_j}{2\alpha}$. Since $\phi^N = \phi_1^N + \phi_2^N$ we deduce that under A1:

$$\phi^N = \frac{\Delta+1}{8\Delta-1}. \tag{12}$$

As in the optimal case (8) the total level of investment ϕ^N decreases with $\Delta \geq 1$.

In section 9.1 we derive the total investment level ϕ^N when transportation costs are positive. Contrarily 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.[14] The larger is Δ, the competitive advantage of firm 1 in term 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 cost implies an increase in the intensity of competition on domestic markets. This business stealing effect discourages firm 1 to invest when free-ridding (i.e. Δ) is large. This effect is also relevant when the advanced economy enforces IPR, but enforcement is imperfect (the case of imperfect enforcement is illustrated in Appendix 9.2).

4.4 Asymmetric IPR protection (P regime)

When only one country protects IPR, firms can imitate their competitors innovation. The quality of good $i = 1, 2$ after investment is given by $\phi^P = \phi_1^P + \phi_2^P$. Moreover both firms can sell in the market in which IPR are not protected. Indeed, IPR are usually well established in developed countries, while less developed ones have lower incentive/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

[14] The total investment level with linear transportation cost $t \geq 0$ is $\phi_t^N = \frac{\Delta+1-\frac{t}{\alpha}\frac{b_1(2\Delta-1)+b_2(2-\Delta)}{b_1 b_2}}{8\Delta-1}$. We deduce that a reduction in t increases ϕ_t^N if and only if $\frac{b_1}{b_2} \geq \frac{\Delta-2}{2\Delta-1}$.

competes with firm 2 in country 2. At the second stage quantities in country 2 are given by the Cournot levels in (4). At the first stage, profit maximization gives the following reaction functions:

$$\phi_1(\phi_2) = \frac{9+4\gamma}{27+32\gamma}(1+\phi_2) \quad (13)$$

$$\phi_2(\phi_1) = \frac{\gamma}{9\Delta(1+\gamma)-\gamma}(1+\phi_1) \quad (14)$$

In the case of partial enforcement of IPR, investments are *strategic complements*. That is, the slope of reaction function is positive for both firms: $\frac{\partial\phi_i(\phi_j)}{\partial\phi_j} > 0 \quad i,j = 1,2 \; i \neq j$. 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 free-riding on the investment of firm 1 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. Solving for the equilibrium, we have:

$$\phi_1^P = \frac{(9+4\gamma)\Delta}{27\Delta+4\gamma(8\Delta-1)} \quad (15)$$

$$\phi_2^P = \frac{4\gamma}{27\Delta+4\gamma(8\Delta-1)} \quad (16)$$

We deduce that the total level of investment $\phi^P = \phi_1^P + \phi_2^P$ is :

$$\phi^P = \frac{9\Delta+4\gamma(1+\Delta)}{27\Delta+4\gamma(8\Delta-1)} \quad (17)$$

It is intuitive in light of the previous results that the total level of investment ϕ^P decreases with $\Delta \geq 1$. More interestingly, and contrary to the other cases F and N, the total level of investment depends on $\gamma = \alpha_2/\alpha_1$. This is because when firm 2 imitates the innovation of firm 1 it cannot export in country 1. It serves only its interior market. Since firm 1 has a monopoly in market 1, it breaks the symmetry between the two markets.

As shown in section 9.1, the introduction of positive transportation costs in this case has a similar effect as under regime F.

4.5 Comparison of investment levels

Comparing the level of investment in the absence of property right protection, (12), with the optimal level of investment (8), 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 when their property rights are not protected. 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. A more interesting issue is whether a stronger enforcement of the IPR regime will help to move the equilibrium level of investment in the right direction, or on the contrary will degrade it. Comparing (8), (12), and (17) it is easy to check that $\phi^* > \phi^P > \phi^N$. Independently of the level of efficiency of the national R&D process, aggregated investment level is always higher under a partial protection regime than under a regime where there is no protection at all. This result gives credit to the idea that a better protection of property rights is conducive to more innovation at the global level. In what follows we assess whether the imposition of the full IPR regime will increase further the global investment in R&D compared to the partial regime, or not. Contrary to what is argued by the proponent of strong enforcement of IPR, it is not always the case that stronger enforcement of IPR increase global investment. In particular the result very much depends on the capacity of each country to do R&D.

Proposition 1 *There is a threshold function $\Delta(\gamma) \in (1, \frac{4}{3})$ 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. The proof is in the appendix. ■

Proposition 1 has interesting implications. First of all, comparing equations (10) with (8), one can check that under assumption 1 the levels of investment in R&D are suboptimal in the case of full protection of IPR: $\phi_2^F < \phi_1^F = \phi^F < \phi^*$. This is worse for the less efficient country. We deduce that, no matter what the IPR regime is, the innovation level is always suboptimal: ϕ^* is larger than all the equilibrium values, ϕ^F, ϕ^N, ϕ^P. Moreover under all regimes, the investment level of country 2 decreases with the ratio Δ (while the investment of country 1 increases).

Second there is a relevant case when developing countries are not doing any R&D (i.e., when $\Delta \to +\infty$). 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 % of global R&D activity. When only the advanced economy, by convention country 1, invests in R&D, which occurs when $\Delta \to \infty$, 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 to do R&D.

Third the imposition of the full IPR regime does not increase the global investment in R&D compared to the partial regime when Δ is small enough. This case is also relevant empirically as emerging countries, such as China or India, have developed world class level R&D systems. When country 2 is able to decrease its technological gap and to develop an efficient $R\&D$ system, global 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, in the Nash equilibrium played by the two competing 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. Thanks to the apparition of new generation of products and/or new applications, in equilibrium the demand is larger so that the firms have more incentive to invest in quality development. In the limit, when the technologies become identical, the global level of investment in the full protection regime F converges towards the low level of the no protection regime N. That is, $\lim_{\Delta \to 1} \phi^F = \phi^N$. Imitation is then preferable because it does not reduce the quality of the product available in the two markets but reduces the total investment costs (they are not duplicated). Therefore the total level of innovation is higher (i.e., it is closer to the first best level) under a partial protection system P than under a full protection system F. This equilibrium does not militate for universal IPR enforcement.

Finally the threshold value so that the innovation level under F becomes larger than the innovation level under P, $\Delta(\gamma)$, increases when the size of the interior market of country 1 rises compared to the interior market of country 2 (i.e., it decreases with the ratio γ). Intuitively, for a given size of the total market, α, when the relative size of market 2 is small, the free-riding problem becomes less important. Firm 2 can only sell in country 2, a small market, and the investment in R&D is less harmed by partial protection of IPR. On the contrary, if market 2 is large, free-riding by firms 2 has a stronger effect on the total incentives to innovate. 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.

The result of Proposition 1 is at the aggregate level and is based on a comparison of all hypothetical regimes. In practice advanced economies have already adopted a policy of strong enforcement of IPR, while developing/emerging countries are not necessarily enforcing them, so that the relevant comparison is between the regimes F and P. In the empirical part, where we rely on data at the country level, we thus focus on these two regimes. Moreover in the base model we have assumed that before investment the two firms have the same quality, normalized to $v_1 = v_2 = 1$. However, in many real word situations, the quality of the two firms will differ ex-ante (i.e. before investment). In the Appendix 9.5 we thus extent the model by assuming that before investment the quality of firm 1 is $v_1 = 1$ and the quality of firm 2 is $v_2 = 1 - d$, where $d \in [0, 1]$ represent the technological gap between the two goods. We also assume that, if imitation occurs, this gap can be closed and everything is as in the base case. However, under regime F, the quality of firm 2 after innovation will be $v_2^F = 1 - d + \phi_2^F$, while the quality of firm 2 is $v_1^F = 1 + \phi_1^F$.

Corollary 1 *Let ϕ_{id}^F denotes the level of investment by firm $i = 1, 2$ when $d \in [0, 1]$.*

- $\phi_{2d}^F \leq \phi^P \ \forall d \in [0, 1]$ *and* $\phi_{2d}^F \leq \phi_2^P \Leftrightarrow d \geq \hat{d} = \frac{27\Delta + 2(6+\Delta)\gamma}{4(27\Delta + 4(8\Delta - 1)\gamma)}$.
- $\phi_{1d}^F \geq \phi_1^P \Leftrightarrow d \geq \tilde{d} = \frac{3\Delta(12+40\gamma - \Delta(44\gamma+9)) - 16\gamma}{6\Delta(\Delta(32\gamma+27) - 4\gamma)}$.

where $\tilde{d} < \hat{d} \leq \frac{1}{4}$

Proof. The proof is in the Appendix 9.5. ■

On the one hand the level of quality obtained by the firm in the developing country is always higher under regime P (i.e., as ϕ_{2d}^F is decreasing in $d \in [0, 1]$ $\phi^P \geq \phi_2^F \geq \phi_{2d}^F$), while by virtue of Proposition 1 it is not always the case for the advanced economy (i.e., if $\Delta > \Delta(\gamma)$ then $\phi^P < \phi^F = \phi_1^F$, which is the value of ϕ_{1d}^F when $d = 0$). On the other hand the level of investment (i.e. the quality developed autonomously by the firm in the developing country) can be higher or lower depending on the existence of the initial gap in the quality levels. The threshold gap $\hat{d}$ is quite low (i.e., $\hat{d} \leq 0.25$) so that in most cases we should observe that, when IPR are better enforced in a developing country, innovation of the local firm decreases. By contrast for the firm in the advanced economy, when IPR are better enforced in the developing country which is a trade partner, we should observe an increase of innovation.

5 Endogenous IPR regimes

In this section we study the choice of IPR regime by utilitarian governments. They make their decision based on domestic criteria. Since advanced economies have already adopted strong IPR regimes, we focus on the case where country 1 (the advanced economy) has a strong IPR regime. The first question we address is whether developing countries will choose to adopt strong IPR regime too or not. In this end we assume that country 2, which is a follower, takes the IPR regime of country 1 as given. It chooses the protection regime F or P which yields the highest national welfare. This in turn influences the level of welfare in country 1, which is derived in order to compute the total welfare in section 5.2 and the optimal IPR regime, F or P, from a global point of view.

5.1 Optimal IPR choice of country 2

The next result establishes that when either γ or Δ is large, regime P might yield a higher welfare for country 2 than regime F and thus become an equilibrium.

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

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

Proof. The proof is in the Appendix 8.2. ■

Country 2 chooses to enforce IPR when its domestic market is relatively small (i.e., when $\gamma = \frac{\alpha_2}{\alpha_1}$ is small). In this case it is very important for country 2 to have access to the market of country 1. This can happen only if country 2 respects IPR. It thus adopts F to be able to trade freely with country 1. By contrast when the size of its national market is large, country 2 can afford not to protect IPR, even if this precludes firm 2 to legally export in country 1. This might explain why fast emerging countries, such as China and India, have been reluctant to enforce IPR as their huge domestic market has developed. This result will be reinforced if illegal imports occur (for instance because as in the case of medicines sell through the internet it is too costly for country 1 to enforce IPR). Then country 2 would choose to protect IPR even less often. Indeed, it can be shown that country 2 always prefers the N regime to the F regime. 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 decrease both in 1 and 2). Imperfect enforcement would correspond to an intermediate case between N and P.

From an empirical point of view, everything else being equal, we expect the degree of enforcement of IPR to be U-shaped in a country market intensity α_i. Poor countries with a small interior market will tend to strictly enforce IPR. Symmetrically rich advanced economies are, for historical reasons, also strictly enforcing IPR. In the middle, emerging countries with large population will tend to free-ride on rich countries innovations by adopting a weak enforcement of IPR.

Finally robustness check shows that if k (and thus Δk) is very large, then country 2 is always better off under regime F. To see this point consider the limit case $k \to \infty$, 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 (37) and (39) in the appendix) 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 this dominance result of F over P still holds for large enough values of k. When k is very large, free-riding on country 1 innovation is not worthwhile, because there is not much to copy. Country 2 always chooses the F regime to be able to export and to sell its production in country 1. However this result is upset when k is small enough, as under Assumption 1.

5.2 Policy adoption and Global welfare

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 need to 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. The next result establishes that indeed the position of the advanced economy vis à vis IPR adoption is sometimes ambiguous.

Proposition 3 *There is a threshold $\gamma_1 > 0$ so 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 $\Delta \geq \Delta_1(\gamma)$.*

Contrary to the developing country, country 1 prefers regime P whenever γ or Δ are small enough. It prefers full enforcement F otherwise. Comparing the results of Propositions 2 and 3, it is clear that there are potential conflicts of interest between the two countries. These conflicts of interest are illustrated Figure 1. Figure 1 represents the welfare gains obtained by country i when the protection regimes shifts from P to F. More specifically, the difference $W_i^F - W_i^P$ is represented. In the shaded regions, country i prefers (F) to (P). In the white region, there is no conflict of interest.

For the sake of the interpretation let focus on the case where α_1 is fixed. 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. For small levels of α_2 (i.e. when the intensity of demand in country 2 is 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

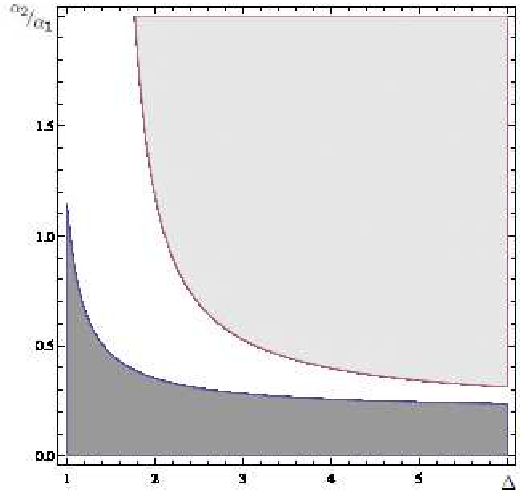

Figure 1: Welfare difference $W_i^F - W_i^P$. In the dark shaded region $W_2^F - W_2^P > 0$ and in the light shaded region $W_1^F - W_1^P > 0$.

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.

Although it is not directly relevant for the empirical application, we conclude the theoretical analysis by a brief presentation of the optimal policy from a collective point of view. This is indeed relevant for possible policy implications. It turns out that $W_1^F + W_2^F$, the total welfare under regime F, hasn't a smooth behavior. For this reason, the comparison with the regime P is not straightforward. Figure 2 illustrates the non-monotonicity of total welfare with respect to γ for high values of Δ (i.e. for high levels of Δ, F is socially preferable than P if γ is either very small or very large). When γ is small, country 2 prefers F and country 1 prefers P but the losses of country 1 are smaller than the gains of 2 and F is preferred from a global point of view. In this case the choice of IPR enforcement by 2 is efficient. On the contrary, when γ is very large (i.e. country 2 is very large or becomes richer), country 1 prefers F and country 2 prefers P, while the losses of country 1 are larger than the gains of country 2. Then F should be preferred at the global level, but country 2 has no incentive to enforce IPR. These results hold true especially when country 2 does not do R&D at all ($\Delta \to \infty$).

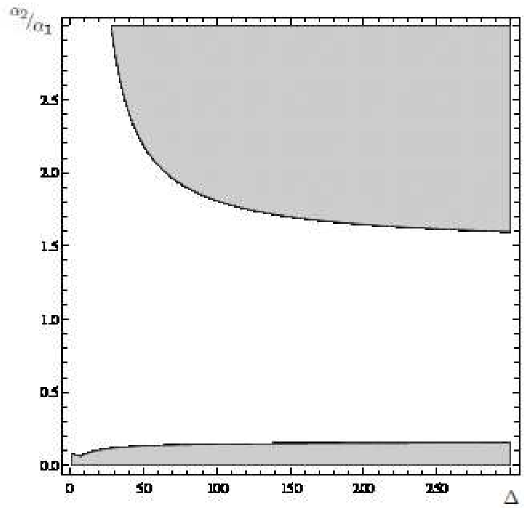

Figure 2: Total welfare difference: $(W_1^F + W_2^F) - (W_1^P + W_2^P)$. In the colored region $(W_1^F + W_2^F) - (W_1^P + W_2^P) > 0$.

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. (i.e. smaller than 0.09). Since developing countries that 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). This dynamics is illustrated by the pharmaceutical industry where a country like India has for decades produced drugs without respecting IPR. This has led western pharmaceutical companies to lobby for a strict enforcement of IPR at the world level. However, now that India has developed a full fledged R&D capacity, it has changed its legislation. As a result of the 2005 new patent legislation, Indian drug firms can no longer copy medicines with foreign patents.[15]

[15] In India, prior to 2005, drug producers could copy patented medicines of foreign firms to create generic by means of alternating production procedures and reverse engineering. This measure was introduced in the seventies by the Government of India to promote the growth of the domestic market and to offer affordable medicine to the population who was unable to afford highly priced foreign drugs. This policy of piracy has boosted the Indian pharmaceutical sector, making it able to address the local market needs

6 Empirical Analysis

6.1 The data

To empirically test the two main predictions of the model, we use several data sources. Data on IPR protection are from Park (2008), who update the index of patent protection published in Ginarte and Park (1997). The original paper presented the index for 1960-1990 for 110 countries. The index has now been updated to 2005 and extended to 122 countries (it is calculated in periods of 5 years).
Trade data is based on COMTRADE, from the United Nations Statistical Department and from the IMF current accounts. These sources contains data from the 1960s to date. More accurate data are derived from the new release of TradeProd (see http://www.cepii.fr), a cross-country dataset developed at CEPII, which integrates information on trade from COMTRADE and industrial production, manufacturing wages and employment levels from UNIDO and OECD-STAN that covers the period 1980-2003. A detailed description of the original sources and procedures is available in Mayer (2008).

For measuring innovation, following Klinger and Lederman (2009, 2011) we distinguish between "inside-the-frontier" innovation and "on-the-frontier" innovation. This distinction is important because in the case of partial enforcement (P), both imitation and incremental innovation take places and not all innovations are patented (because imitating firms cannot patent their innovation). Klinger and Lederman (2009, 2011) propose export discoveries, i.e. the discovery of products for exports that have been invented abroad but that are new to the country, as a measure of "inside-the-frontier" innovations. It is measured by the number of new products that enter a country's export basket in any given year, calculated using trade data from COMTRADE and BACI-CEPII (for more details on the construction of the variable, see Appendix 9.7). The use of export discoveries as a measure of "inside-the-frontier" innovation is inspired by the work of Imbs and Wacziarg (2003). In this paper, the authors show that economic development is associated with increasing diversification of employment and production across industries rather than specialization (something similar to horizontal innovation). Klinger and Lederman (2009, 2011) studies one aspect of economic diversification, namely the

with surpluses that facilitated exports.

introduction of new export products. One problem recognized by the authors is that, contrarily to production discoveries, a product emerging as a new export may have been produced domestically for some time, and therefore would not represent a genuine discovery. In our case, this element makes export discoveries an even more appealing proxy for "within-the-frontier" innovation in the sense of our paper (i.e. driven by imitations). In fact, countries are known to export those goods in which they become the most productive, as argued by Hausmann, Hwang, and Rodrik, 2007. Then, innovation in the production of goods that are not on the technological frontier, but are obtained mainly imitating foreign technology, can be captured by this measure of export innovations. Following our model, we expect that this underestimates total innovation, because some of the goods developed by imitation couldn't be (legally) exported to many countries. It is nonetheless the best proxy we could find, because comparable data on production are not available.

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

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

The analysis make a distinction between developed and developing countries. For each year in our sample, we consider that a country is developed if it belongs to the highest quintile in term of GDP per capita. We discard oil-exporting countries exhibiting very high GDP per capita levels (higher than 40000 USD of 2000). All these countries, at the exception of Norway, which is included as a developed country in the regressions, are highly dependent on this commodity (measured as a share of exports) and exhibit a low diversification of their economies.[16]

[16] Norway is included as developed country in the regressions, but it is not considered in the distribution to set the threshold in year 2005 because its GDP per capita exceeds 40000 USD.

6.2 Empirical results

Our theoretical analysis encompasses three regimes, full F, partial P and no N protection. However, regime N is not directly relevant for empirical analysis, because in practice developed countries have already adopted strong IPR protection. When testing the empirical prediction of the model, we mainly compare regimes P and F, still taking into account the possible impact of illegal imports on the magnitude of the results.[17]

Our model predicts that countries with a relatively small internal market compared to their trade partners prefer to enforce patent rights, while countries with a larger internal market become less willing to enforce strictly IPR. By contrast, developed countries always protect IPR. Then, the first empirical implication of the model is that patent enforcement should be a U-shaped function of the size of the internal market. The access to foreign market has the opposite effect, increasing the relative importance of exports with respect to domestic sales (i.e., inverse U-shaped function).

To test this prediction we use the information about per-capita GDP (variable GDPPC) and population (POP). In our model, the variable α_i, the intensity of demand in the domestic market, is represented by the ratio a_i/b_i where a_i is interpreted as the inverse of the marginal utility of income and b_i as the inverse of the population size. Assuming the utility of income is logarithmic, α_i corresponds to the total GDP.[18] We name the empirical equivalent of α_i as ALPHA=GDPPC * POP.

The results of the performed regressions are presented in Table 1. Exploiting the panel dimension of our database all the regressions include country fixed effect and time effect. Standard errors are robust and clustered by country. Continuous variables are in logs. To avoid possible endogeneity problems, the variables describing the market size

[17] The analysis of the N regime is a limit case useful to understand the impact of imperfect enforcement and illegal imports, when the actual regime is P (see Appendix 9.2).

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

$$u(R) = \begin{cases} \frac{(R^(1-\rho)-1}{1-\rho}, & \text{if } \rho \neq 1; \\ log(R), & \text{if } \rho = 1. \end{cases} \tag{18}$$

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

are lagged 5 years.[19] In column (a) we regress IPR against the size of the internal market $ALPHA = GDPPC * POP$ and its square. We expect the coefficient of $ALPHA$ to be negative and the coefficient of $ALPHA^2$ to be positive, which is confirmed by the estimation.

In column (b) we add a measure of the foreign market size, denoted F-ALPHA, which is a proxy for α_j. Following Head and Mayer, 2004 and Redding and Venables, 2004, we construct a measure of the foreign market potential (or foreign market access), denoted $F - ALPHA$, using a methodology developed in the new economic geography literature, based on the estimation of bilateral trade equations. In our case, we define

$$F - ALPHA = \sum_{j \neq i} GDP_j \hat{\phi}_{ij}, \tag{19}$$

where $\hat{\phi}_{ij}$ includes bilateral distances, contiguity, common language, regional trade agreements, WTO affiliation and a national border dummy (for more details on the construction of $F - ALPHA$ see appendix 9.6). In our specification, we expect the coefficient of $F - ALPHA$ and $F - ALPHA^2$ to have opposite sign with respect to the own market variables, $ALPHA$ and $ALPHA^2$, which is confirmed by the estimation.

In column (c) we add an economic freedom index ($lnfreedom$) and a dummy indicating the year of entry in the GATT or later in the WTO ($gatt/wto$) as additional controls. It is intuitive that these two variables should influence positively the level of enforcement of IPR. It is thus unsurprising that the coefficient of these controls is positive and significant. More importantly for our analysis the signs of $ALPHA$, $F - ALPHA$ and squared, do not change.

These empirical results confirms the existence of a U-shaped relationship between patent protection and GDP. This result is consistent with previous empirical studies by Maskus (2000) and Braga, Fink, and Sepulveda (2000). These papers were the first to identify a U-shaped relationship between IPRs enforcement and per-capita income. Chen and Puttitanun (2005) propose a theoretical fondation to this empirical finding, that they confirm in their own empirical application. These three pioneer papers focus on domestic

[19] Theoretically, strong IPR protection could stimulate new investment and/or FDI and in turn affect GDP. This channel is likely to take some time, and we reduce the risk of endogeneity lagging the variables. We recognize that this not fully ensure exogeneity. However, our specification is based on the implications of our theoretical model and on the existing literature on IPRs (e.g., Ginarte and Park, 1997; Maskus, 2000; Chen and Puttitanun, 2005).

Table 1: IPR Equation

	(a)	(b)	(c)	(d)	(e)	(f)
	b/se	b/se	b/se	b/se	b/se	b/se
LagALPHA	–2.24*	–1.20	–2.28***	–1.42	–4.42***	–6.40**
	(0.40)	(0.88)	(1.30)	(1.87)	(2.43)	(2.76)
LagALPHA^2	0.05*	0.03	0.05**	0.04	0.10***	0.14**
	(0.01)	(0.02)	(0.03)	(0.04)	(0.05)	(0.06)
LagF-ALPHA		3.32*	3.05**	3.25*	2.96**	–3.00
		(1.21)	(1.19)	(1.13)	(1.38)	(2.87)
LagF-ALPHA^2		–0.07**	–0.07**	–0.08*	–0.07**	0.08
		(0.03)	(0.03)	(0.03)	(0.03)	(0.07)
freedom			0.57***	0.62***	0.48	0.29
			(0.31)	(0.31)	(0.44)	(0.47)
gatt/wto			0.43*	0.45*	0.64*	0.58*
			(0.15)	(0.15)	(0.17)	(0.17)
hcap				–0.76	–0.03	0.15
				(1.28)	(1.45)	(1.53)
hcap^2				0.02	–0.03	–0.07
				(0.06)	(0.07)	(0.08)
Lagfstud-F					–7.49**	–9.40**
					(3.40)	(3.94)
Lagspgatt-F					0.30***	0.30***
					(0.18)	(0.18)
Time dummies	yes	yes	yes	yes	yes	yes
Country fixed effect	yes	yes	yes	yes	yes	yes
No. of obs	906	553	511	493	362	289
Adj. R^2	0.74	0.67	0.71	0.71	0.74	0.76

Robust Standard Errors in parentheses, clustered by country. ***, ** and * represent respectively statistical significance at the 1%, 5% and 10% levels.

market.[20] The novelty of our paper is to consider an economy where both the advanced economy and the developing country can import and export. Our analysis hence shows that the measure of the foreign market potential $F - ALPHA$ is key to explain IPR enforcement at the domestic level. As predicted by the theory, the empirical analysis confirms the existence of an inverse U-shaped relationship between patent protection and $F - ALPHA$.

[20] In the two sectors (import and domestic) model of Chen and Puttitanun (2005), the level of innovation in the developed countries is considered as fixed and firms in the developing country produce only for local consumers (no export). In the empirical applications, as in Maskus (2000) and Braga, Fink, and Sepulveda (2000), the focus is on the relationship at a country level between IPRs enforcement and domestic per-capita income. In our analysis we consider the size of the population along with the per-capita income, which is the traditional measure of the level of development, as they are both relevant demand characteristics in the context of international trade.

The second set of testable implications are from Corollary 1. The bottom line is that a stricter enforcement of IPR is not necessarily conducive of more innovation at the country level, and in fact, by virtue of Proposition 1, not even at the global level. From an empirical point of view trying to assess the impact of IPR on innovation poses problems of endogeneity. According to the theory, the innovation equation should be estimated simultaneously to the equation describing the choice of IPR. However, many of the variables used to explain IPR and presented in Table 1 columns (a)-(c), are likely to be explanatory variable of innovation as well, and do not represent valid instruments for IPR in the innovation equation. We thus instrument IPR using an additional set of instruments which satisfies the exclusion restriction from the innovation equations (tested using the Hansen J-statistics). The first instrument is $gatt/wto$: entering into the gatt agreements or in the wto imposes higher IPR standards to countries. The second instrument captures entry in the gatt/wto of other countries, weighted by distance (Lagspgatt-F). In fact, entry in the gatt/wto of other countries, especially neighbors and/or trade partners, can also progressively affect the country decision to enforce IPR (this instrument is lagged 10 years).

The third instrument, $Lagfstud - F$, is the number of students from the neighbor countries, always weighted by distance, who study in foreign democracies (as measured by the freedom-house indicator). The instrument is lagged 10 years. We focus on students from neighbor countries instead of students from the home country because the volume of students a country chooses to send abroad is presumably endogeneous to the choice of its IPR policy. We use instead the number of students sent by its neighbors to foreign democracies, as they indirectly impact the domestic choice of IPR. On the one hand, there are several studies showing that students who spent time abroad can influence the development of institutions in their home country (see Spilimbergo (2009)).[21] Recently, Naghavi and Strozzi (2011) show that the knowledge acquired by emigrants abroad can flow back home into the innovation sector, but only when IPR protection in the sending country is sufficiently strong. This is in line with the findings of Santos and Postel-

[21]Spilimbergo (2009) shows that individuals educated in foreign democratic countries can promote democracy in their home country. Similarly, the same individuals, exposed to a full set of institutions, often including well-protected property rights, can also have an impact on the diffusion of attitudes towards IPR.

Vinay (2003) and Dustmann, Fadlon, and Weiss (2010), who put the accent on the positive effects of technology-transfers and return migration. Following Naghavi and Strozzi (2011), we then restrict the attention to countries belonging to gatt/wto (i.e. the variable describing the number of foreign student is interacted with gatt/wto). The idea is that migration can cause technology transfers, but this effect is significant only in countries which already enforce sufficiently IPR (to confirm this intuition, we also try to include migrants from countries not belonging to gatt/wto, but the variable is statistically rejected as valid instrument). On the other hand, if these students help the neighbor country to import technology, this will have an impact on the technological gap between the home country and its neighbor (either positive, if there are imitation and spillovers, or negative through competition effect). Similarly, if these returning students induce the adoption of institutions such as IPR in the neighbor countries, this will also affect the enforcement of IPR in the home country.

To sum up, we estimate the impact of stricter enforcement of IPR on inside/on-the-frontier innovations using a two-stage least square procedure, using the variables $gatt/wto$, $Lagspgatt - F$, $Lagfstud - F$ as excluded instruments. All the remaining variables are included both in the IPR (first stage) and in all innovation equations. In particular in column (d) table 1 we show the basic IPR regression controlled for the stock of human capital, $hcap$ and its square. The variable $hcap$ is the level of human capital computed with Hall & Jones method using the new series proposed in Barro and Lee, 2010. This variable does not appear to be significant and is clearly collinear with the size of internal demand $ALPHA$. However, as the variable has an autonomous role in explaining "on-the-frontier" innovation of firms from developing countries in Table 2, we have included it in the first stage equation (explaining IPR) consistently with the two-stage least squares procedure.

The results of the first stage equation explaining IPR including the two new instruments are reported in column (e) and (f) of Table 1. In column (e) the regression is for the full sample and in column (f) it is restricted to the sub-sample of less developed countries (i.e., the countries which belong to the last 4 quintile in term of gdp per capita distribution see Section 6.1). Human capital $hcap$ is also controlled for.

Corollary 1 has two broad set of implications. The first one is on the level of innovation incorporated in the production of the firm in the developing country. The corollary states that this level is higher when the developing country does not enforce IPR than when it does enforce them: $\phi_2^F \leq \phi^P$.[22] In order to assess the relevance of this prediction we rely on inside-the-frontier innovation, as measured by discoveries (i.e. the goods that are new in the export basket of a country, although already produced abroad) in developing countries. For these countries, discoveries can be considered a proxy for inside-the-frontier innovation (see Klinger and Lederman, 2009). The results are presented in Table 2. Fixed effects and time dummies are included in all specifications. For the sake of comparison we show in column (a) the result of the regression when we do not correct for the endogeneity of IPR. In column (b) IPR is instrumented using $gatt/wto, Lagspgatt-F, Lagfstud-F$. As expected from the theory, increasing IPR protection decreases within-the-frontier innovation. We interpret this result as evidence that stricter IPR protection, forbidding imitation and reverse engineering, reduces the quality of domestic goods in developing countries.

The second set of implications focuses on the level of investment in R&D and the quality developed autonomously by the firm in the developing country (i.e. on-the-frontier innovation). Starting from a situation where there is an initial gap in the quality levels produced by developed and developing countries, we predict that, when IPR are enforced more strictly innovation of the local firm decreases in the developing country, while the one of the firms of the developed world should increase. More protection can slow down on-the frontier-innovation because of the initial gap in the quality produced (see Appendix 9.5). To test this second set of predictions, we use data on patents as a proxy for on-the-frontier innovation. We focus on the subsample of less developed countries (see Section 6.1) and we measure the on-the-frontier innovation of resident firms as the number of patents application made by residents. Symmetrically, innovations made by firms from the developed countries are proxied by the number of patents applications made by non-resident firm. In fact, in developing (and developed) countries, most of the patents of non-resident firms are registered by firms coming from developed countries. As before we show first (i.e., in columns (a), (b) (c)) the result of the regressions when we do not

[22] The condition of Corollary 1 is $\phi_{2d}^F \leq \phi^P \ \forall d \geq 0$. Since ϕ_{2d}^F decreases in d implies that $\phi_2^F = \phi_{20}^F \geq \phi_{2d}^F$, we deduce the result.

Table 2: Discoveries Equation

	(a)	(b)
	b/se	b/se
ipr	–0.06	–0.42**
	(0.09)	(0.20)
LagALPHA	6.10*	8.62*
	(2.07)	(2.61)
LagALPHA^2	–0.13*	–0.18*
	(0.04)	(0.05)
LagF-ALPHA	3.43**	5.17*
	(1.40)	(1.81)
LagF-ALPHA^2	–0.09*	–0.14*
	(0.03)	(0.04)
freedom	0.56***	0.56
	(0.32)	(0.40)
hcap	4.07**	2.42
	(2.02)	(1.93)
hcap^2	–0.15	–0.10
	(0.11)	(0.10)
Time dummies	yes	yes
Country fixed effects	yes	yes
IPR endogenous	no	yes
No. of obs	454	356

Robust Standard Errors in parentheses, clustered by country. ***, ** and * represent respectively statistical significance at the 1%, 5% and 10% levels.

Table 3: Patent Equation

	(d)Res	(e)NRes	(f)All	(g)Res	(h)NRes	(i)All
	b/se	b/se	b/se	b/se	b/se	b/se
ipr	–0.47*	0.17	0.03	–1.14*	0.80**	0.36
	(0.10)	(0.12)	(0.11)	(0.33)	(0.35)	(0.25)
LagALPHA	–5.71	–1.41	2.20	–17.88**	–0.15	1.95
	(4.40)	(6.07)	(5.98)	(8.26)	(6.44)	(6.14)
LagALPHA^2	0.15***	0.04	–0.02	0.40**	–0.00	–0.03
	(0.09)	(0.12)	(0.12)	(0.17)	(0.14)	(0.13)
LagF-ALPHA	–0.59	4.80	2.77	5.20	8.80**	6.64**
	(2.94)	(3.74)	(3.57)	(3.36)	(4.42)	(2.96)
LagF-ALPHA^2	0.02	–0.11	–0.06	–0.12	–0.19***	–0.15**
	(0.07)	(0.09)	(0.09)	(0.08)	(0.11)	(0.07)
freedom	0.72**	–0.38	0.57	0.52	–0.69	0.36
	(0.28)	(0.65)	(0.37)	(0.45)	(0.58)	(0.34)
hcap	3.82	0.59	0.84	9.09**	–2.16	–0.04
	(2.33)	(1.71)	(1.74)	(3.55)	(2.48)	(2.40)
hcap^2	–0.11	0.01	0.03	–0.40**	0.22	0.12
	(0.11)	(0.10)	(0.08)	(0.17)	(0.17)	(0.14)
Time dummies	yes	yes	yes	yes	yes	yes
Country fixed effect	yes	yes	yes	yes	yes	yes
IPR endogenous	no	no	no	yes	yes	yes
No. of obs	244	258	242	184	196	182

Robust Standard Errors in parentheses, clustered by country. ***, ** and * represent respectively statistical significance at the 1%, 5% and 10% levels.

correct for the endogeneity of IPR, and next in column (d), (e), (f), IPR is instrumented using $gatt/wto, Lagspgatt - F, Lagfstud - F$. The results, shown in Table 3, show that neglecting to correct for endogeneity biases downward the impact of IPR on innovation. More importantly it confirms that increasing IPR enforcement decreases on-the-frontier innovation of resident firms in developing countries (resident patents) but increases innovation of nonresident firms (which are mostly firms based in developed countries). The impact of IPR enforcement on total patents is not significant.

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.

The main predictions of the model have been tested empirically on trade data offering support to the main insight of the theoretical analysis.

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8 Appendix

8.1 Proof of Proposition 1

Comparing equation (12) with (17) 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 (8) with (17), $\phi^P < \phi^*$ 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 $k_2 > k_1 \geq 0$. QED

We already established that $\phi^N \leq \phi^P \leq \phi^*$. We need to check when $\phi^P \leq \phi^F$. Let $\gamma = \frac{\alpha_2}{\alpha_1}$ so that:

$$\alpha_2 = \gamma \alpha_1 \quad \text{with} \quad \gamma > 0. \tag{20}$$

Then, γ captures the relative intensity of demand in country 2. Under Assumption 1 we can rewrite the relevant innovation levels. Under regime (F) we have

$$\phi_1^F = \frac{6\Delta - 4}{15\Delta - 8} \tag{21}$$

$$\phi_2^F = \frac{2}{15\Delta - 8} \tag{22}$$

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 1, 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) we have, $\phi_1^N = \frac{\Delta}{8\Delta-1}$ and $\phi_2^N = \frac{1}{8\Delta-1}$ so that

$$\phi^N = \frac{\Delta + 1}{8\Delta - 1} \tag{23}$$

Under regime (P) we have, $\phi_1^P = \frac{(9+4\gamma)\Delta}{27\Delta+4\gamma(8\Delta-1)}$ and $\phi_2^P = \frac{4\gamma}{27\Delta+4\gamma(8\Delta-1)}$ so that

$$\phi^P = \frac{9\Delta + 4\gamma(1 + \Delta)}{27\Delta + 4\gamma(8\Delta - 1)} \tag{24}$$

It is easy to check that investment of firm 2 increases more when γ increases (i.e. $\frac{\partial \phi_1^P}{\partial \gamma} \geq \frac{\partial \phi_2^P}{\partial \gamma} \geq 0$). It is straightforward to check that $\phi_2^P \leq \phi_2^F \leq \phi^P$. Moreover, comparing equation (21) with (24) one can easily check that:

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

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. We deduce that $\hat{\Delta}(\gamma) \in [1, 4/3]$. QED

8.2 Proof of Proposition 2

Before computing national welfare to see what type of IPR regime developing countries are likely to favor we compute first the industry profit associated with each type of regime.

8.2.1 Firms' Profits

We first 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 will make pressure on governments, for instance through lobbying, to push for the protection regime that favors them most. Moreover, if the government of country 2 finds that it is optimal not to enforce IPR, and thus favors the regime P, the firm in country 2 mights still want to respect the country 1 IPR in order to be able to export. We thus need to compute firm 2 profits to integrate this incentive constraint in the welfare maximization problem of country 2. In a nutshell a government can oblige a firm to respect IPRs but it cannot oblige it to violate them.

Proposition 4 *Assume A1 holds. There exist two thresholds* $0 < \underline{\gamma}_2 < \overline{\gamma}_2$ *so that:*

- *If* $0 < \frac{\alpha_2}{\alpha_1} < \underline{\gamma}_2$ *then* $\pi_2^F > \pi_2^P$*;*

- *If* $\underline{\gamma}_2 \leq \frac{\alpha_2}{\alpha_1} \leq \overline{\gamma}_2$ *then there exists a threshold value* $\Delta_2(\frac{\alpha_2}{\alpha_1})$ *such that* $\pi_2^F \geq \pi_2^P$ *if and only if* $\Delta \leq \Delta_2(\frac{\alpha_2}{\alpha_1})$*;*

- *If* $\frac{\alpha_2}{\alpha_1} > \overline{\gamma}_2$ *then* $\pi_2^F < \pi_2^P$*.*

Proof. We analyze the effect of the different protection regimes on the profit of firm 2. Let $\gamma = \frac{\alpha_2}{\alpha_1}$ (see (20)). Under Assumption 2, we have:

$$\pi_2^F = \frac{\alpha\Delta(9\Delta - 4)}{(15\Delta - 8)^2} \tag{25}$$

$$\pi_2^P = \frac{16\alpha\gamma\Delta(9(1+\gamma)\Delta - \gamma)}{(27\Delta + 4\gamma(8\Delta - 1))^2} \tag{26}$$

$$\pi_2^N = \frac{\alpha\Delta(9\Delta - 1)}{(8\Delta - 1)^2} \tag{27}$$

Comparing equation (25) with (26), it is straightforward to verify that:

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

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 $\Delta_1(\gamma)$ such that $\pi_2^F - \pi_2^P$ if and only if $\Delta \leq \Delta_1(\gamma)$. Finally, if $\gamma > 1.36$ $\pi_2^F - \pi_2^P$ is always negative.
Finally, from equations (25) and (27) one can easily verify that the difference $\pi_2^F - \pi_2^N$ is always negative. ■

Proposition 4 shows that if the interior market of country 2 is small compared to the market of country 1 (i.e., if $\alpha_2 < \alpha_1\underline{\gamma}_2$) then the firm in country 2 prefers to respect firm 1 IPR in order to be able to export in country 1. This is a case where government of country 2 will have to internalize this constraint in its optimization problem. From a concrete point of view the appendix shows that $\underline{\gamma}_2 \simeq 0.28$ so that "small" means roughly 1/3. Symmetrically, if the interior market of country 2 is large compared to the market of country 1 (i.e., if $\alpha_2 > \overline{\gamma}_2\alpha_1$) then the firm in country 2 prefers to copy firm 1 innovation and to focus on its interior market. The appendix shows that $\overline{\gamma}_2 \simeq 1.3$ so that "large" means roughly 1.5. For market size of intermediate values the optimal decision for the firm depends on its technology.

The best regime for firm 2 should not be the same as the best regime for firm 1. Their interests tend indeed to be antagonist. However an interesting question is whether firm 1 is always penalized by a weaker enforcement of IPR (i.e., by the F regime). It turns out that it is not always the case.

Proposition 5 *Assume that A1 holds. There is a threshold $\gamma_1 > \overline{\gamma}_2$ so that:*

- *If $\frac{\alpha_2}{\alpha_1} \leq \gamma_1$ then $\pi_1^P > \pi_1^F$;*
- *If $\frac{\alpha_2}{\alpha_1} > \gamma_1$, there exists a threshold value $\Delta_1(\frac{\alpha_2}{\alpha_1})$ such that $\pi_1^F \geq \pi_1^P$ if and only if $\Delta \geq \Delta_1(\frac{\alpha_2}{\alpha_1})$.*

Proof. We analyze the effect of the different protection regimes on the profit of firm 1. Let $\gamma = \frac{\alpha_2}{\alpha_1}$ (see (20)). Under Assumption 2, one can check that:

$$\pi_1^F = \frac{5\alpha(3\Delta-2)^2}{(15\Delta-8)^2} \tag{28}$$

$$\pi_1^P = \frac{\alpha(9+4\gamma)(27+32\gamma)\Delta^2}{((8\Delta-1)4\gamma+27\Delta)^2} \tag{29}$$

$$\pi_1^N = \frac{8\alpha\Delta^2}{(8\Delta-1)^2} \tag{30}$$

Comparing equation (28) with (29), it is straightforward to verify that:.

$$(\pi_1^F - \pi_1^P)|_{\Delta\to 1} = -\frac{6\alpha(9+4\gamma)}{49(28\gamma+27)^2} \leq 0$$

$$(\pi_1^F - \pi_1^P)|_{\Delta\to \infty} = -\frac{6\alpha(3-2\gamma)}{25(32\gamma+27)^2}$$

$$\frac{\partial(\pi_1^F - \pi_1^P)}{\partial\Delta} = 4\alpha\left(\frac{15(3\Delta-2)}{(15\Delta-8)^3} + \frac{2\gamma(9+4\gamma)(27+32\gamma)\Delta}{(27\Delta+4\gamma(8\Delta-1))^3}\right) \geq 0$$

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 (28) and (30) one can easily verify that the difference $\pi_1^F - \pi_1^N$ is positive if and only if $\Delta \geq 1.5$. ■

When the interior market of country 2 is small compared to the interior market of country 1 (i.e., when $\alpha_2 < \alpha_1 \underline{\gamma}_2$), firm 1 prefers a partial protection regime, F. Moreover, 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 $\frac{\alpha_2}{\alpha_1}$, 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.

8.3 Consumer surplus

We now look at the effect of the protection regime on consumer surplus.

Proposition 6 *Assume A1 holds. Then, regime (F) is always preferred to regime (N) by consumers in both countries. Moreover, for consumers in country 1 regime (N) is preferred to (P). For consumers in country 2, there exists a threshold* $\gamma_{s2} = 1.5$ *such that:*

- *If* $\frac{\alpha_2}{\alpha_1} \leq \gamma_{s2}$, *regime (P) is preferred to regime (F);*
- *If* $\frac{\alpha_2}{\alpha_1} > \gamma_{s2}$, *there exists a threshold value* $\tilde{\Delta}_{s2}(\frac{\alpha_2}{\alpha_1}) = \frac{8\frac{\alpha_2}{\alpha_1} - 5 - \sqrt{16\frac{\alpha_2}{\alpha_1} + 25}}{8\frac{\alpha_2}{\alpha_1} - 12}$ *such that regime (F) is preferred to regime (P) if and only if* $\Delta \geq \tilde{\Delta}_{s2}(\frac{\alpha_2}{\alpha_1})$.

Proof. Let $\gamma = \frac{\alpha_2}{\alpha_1}$ (see (20)). Under assumption 2, we have:

$$S_2^F = \frac{18\gamma\alpha_1(2\Delta - 1)^2}{(15\Delta - 8)^2} \quad (31)$$

$$S_2^P = \frac{288\gamma\alpha_1\Delta^2(1+\gamma)^2}{(\Delta(27 + 32\gamma) - 4\gamma)^2} \quad (32)$$

$$S_2^N = \frac{18\gamma\alpha_1\Delta^2}{(8\Delta - 1)^2} \quad (33)$$

$$S_1^F = \frac{18\alpha_1(2\Delta - 1)^2}{(15\Delta - 8)^2} \tag{34}$$

$$S_1^P = \frac{162\alpha_1\Delta^2(1+\gamma)^2}{(\Delta(27+32\gamma) - 4\gamma)^2} \tag{35}$$

$$S_1^N = \frac{18\alpha_1\Delta^2}{(8\Delta - 1)^2} \tag{36}$$

Comparing equation (34) with (35) et (36), it is straightforward to verify that $S_1^F \geq S_1^N \geq S_1^P$. Similarly, comparing equation (31) with (36) it is clear that $S_2^F \geq S_2^N$. Moreover, for $\gamma \leq 1.5$, $S_2^P \geq S_2^F$. For $\gamma > 1.5$, $S_2^P \geq S_2^F$ if and only if $\Delta \leq \frac{8\gamma-5+\sqrt{16\gamma+25}}{8\gamma-12}$. ■

We have shown that regime (N) is always the least preferred for consumers. The reason is that under this regime innovation is very low and thus the quality of the good is poor. Moreover, consumers of country 1 are better off under (F) than under (P). The reason is that under (P) firm 2 cannot trade in country 1, and firm 1 is a monopoly. Than, the price is high and consumer surplus decreases. On the other hand, consumers of country 2 might be better off under (P). The reason is that when firm 2 imitates, competition increases in 2, increasing consumer surplus. However, when the size of demand in 2 becomes large ($\frac{\alpha_2}{\alpha_1} > 1.5$), and firm 2 does not innovate much (Δ large), we know that under regime (P) innovation is much lower than in (F). Then, even consumers of country 2 prefers regime (F) in this case.

8.4 Proof of Proposition 2

Let $\gamma = \frac{\alpha_2}{\alpha_1}$ (see (20)). Under full protection of IPR (F), welfare in country $i = 1, 2$ can be written:

$$W_i^F = \frac{1}{18}\left[3\alpha_i\Big(2(1+\phi_i^F)^2 + (\phi_i^F - \phi_j^F)^2\Big) + 2\alpha_j(1 + 2\phi_i^F - \phi_j^F)^2\right] - k_i\frac{(\phi_i^F)^2}{2} \tag{37}$$

While under no protection (N) :

$$W_i^N = \frac{1}{9}(3\alpha_i + \alpha_j)(1 + \phi_1^N + \phi_2^N)^2 - k_i\frac{(\phi_i^N)^2}{2} \tag{38}$$

Finally, under partial protection (P) welfare of country 2 is:

$$W_2^P = \frac{1}{3}\alpha_2(1 + \phi_1^P + \phi_2^P)^2 - \Delta k\frac{(\phi_2^P)^2}{2} \tag{39}$$

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

$$W_2^F = \frac{\alpha(\gamma(\Delta(81\Delta-76)+18)+\Delta(9\Delta-4))}{(\gamma+1)(8-15\Delta)^2} \quad (40)$$

Under partial protection (P):

$$W_2^P = \frac{16\alpha\gamma\Delta(27(\gamma+1)\Delta-\gamma)}{(4\gamma(8\Delta-1)+27\Delta)^2} \quad (41)$$

Finally, under no protection (N):

$$W_2^N = \frac{\alpha\Delta(\gamma(27\Delta-1)+9\Delta-1)}{(\gamma+1)(1-8\Delta)^2} \quad (42)$$

Comparing equation (40) with (41) it is straightforward to verify that:

$$(W_2^F - W_2^P)|_{\Delta\to 1} = \frac{\alpha(3645-3\gamma(56\gamma(14\gamma+17)-1053))}{49(\gamma+1)(28\gamma+27)^2}$$

$$(W_2^F - W_2^P)|_{\Delta\to \infty} = \frac{\alpha(729-\gamma(16\gamma(99\gamma+314)+2511))}{25(\gamma+1)(32\gamma+27)^2}$$

$$\frac{\partial(W_2^F - W_2^P)}{\partial\Delta} = \frac{4\alpha\left(\gamma\left(\frac{20\gamma(\gamma+1)(4\gamma(46\Delta-1)+189\Delta)}{(4\gamma(8\Delta-1)+27\Delta)^3}+\frac{85-195\Delta}{(15\Delta-8)^3}\right)-\frac{5(21\Delta-8)}{(15\Delta-8)^3}\right)}{5(\gamma+1)}$$

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.

Moreover, we have:

Moreover, for a fixed level of Δ, $W_2^F - W_2^P$ is a decreasing and convex function of $\gamma = \frac{\alpha_2}{\alpha_1}$.

$$\frac{\partial(W_2^F - W_2^P)}{\partial\gamma} = \alpha_1[-\frac{1458(5x-4)(5x-3)x^3+27((159-245x)x+8)x^2}{(1-8x)^2(x(32\gamma+27)-4\gamma)^3} - \frac{x(x((891x-545)x-481)+300)-18}{(120x^2-79x+8)^2}] < 0$$

$$\frac{\partial^2(W_2^F - W_2^P)}{\partial\gamma^2} = \alpha_1[\frac{864x^2\left(5x^2(49\gamma+54)-3x(53\gamma+63)-8\gamma\right)}{(x(32\gamma+27)-4\gamma)^4}] > 0$$

Then, the welfare gains of country 2 are a decreasing an concave function of the parameter $\gamma = \frac{\alpha_2}{\alpha_1}$. QED

8.5 Proof of Proposition 3

Let $\gamma = \frac{\alpha_2}{\alpha_1}$ (see (20)). Under full protection of IPR (F), welfare in country $i = 1$ is defined in (37), and under no protection (N) it is defined in (38), while under partial protection (P) it is:

$$W_1^P = \frac{1}{72}(27\alpha_1 + 8\alpha_2)(1 + \phi_1^P + \phi_2^P)^2 - k_1\frac{(\phi_1^P)^2}{2} \tag{43}$$

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

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

Under partial protection (P):

$$W_1^P = \frac{\alpha(2\gamma(64\gamma + 279) + 405)\Delta^2}{(4\gamma(8\Delta - 1) + 27\Delta)^2} \tag{45}$$

Finally, under no protection (N):

$$W_1^N = \frac{2\alpha(4\gamma + 13)\Delta^2}{(\gamma+1)(1-8\Delta)^2} \tag{46}$$

Comparing equation (44) with (45) it is straightforward to verify that:

$$\begin{aligned}
(W_1^F - W_1^P)|_{\Delta\to 1} &= -\frac{6\alpha(\gamma(7\gamma(56\gamma + 191) + 1461) + 513)}{49(\gamma+1)(28\gamma+27)^2} \\
(W_1^F - W_1^P)|_{\Delta\to\infty} &= \frac{\alpha(2\gamma(\gamma(960\gamma + 2401) + 1017) - 648)}{25(\gamma+1)(32\gamma+27)^2} \\
\frac{\partial(W_1^F - W_1^P)}{\partial\Delta} &= \frac{4\alpha}{5(\gamma+1)}(5\gamma\Big(\frac{2(\gamma+1)(2\gamma(64\gamma+279)+405)\Delta}{(4\gamma(8\Delta-1)+27\Delta)^3} \\
&\quad + \frac{15(3\Delta-2)}{(15\Delta-8)^3}\Big) + \frac{15(9\Delta-7)}{(15\Delta-8)^3}\Big)
\end{aligned}$$

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

8.6 Proof of Proposition 7

We formally establish local results:

Proposition 7 *Assume that assumption 1 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* $\frac{\alpha_2}{\alpha_1} \leq \gamma_1^{ii}$.
- *If* $\Delta \to \infty$ *then* $(W_1^F + W_2^F) > (W_1^P + W_2^P)$ *if and only if* $\frac{\alpha_2}{\alpha_1} \leq \gamma_2^{ii}$ *or* $\frac{\alpha_2}{\alpha_1} \geq \gamma_3^{ii}$

Proof. ■

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.

Let $\gamma = \frac{\alpha_2}{\alpha_1}$ (see (20)). Using equations (44), (45), (40) and (41) one can verify that:

$$\begin{aligned} (W_1^F + W_2^F) - (W_1^P + W_2^P)|_{\Delta \to 1} &= -\frac{\alpha(42\gamma(16\gamma + 21) - 81)}{7(28\gamma + 27)^2} \\ (W_1^F + W_2^F) - (W_1^P + W_2^P)|_{\Delta \to \infty} &= \frac{3\alpha(2\gamma - 3)(56\gamma - 9)}{25(32\gamma + 27)^2} \end{aligned}$$

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 2.QED

9 Robustness Checks

9.1 Variable Transportation Cost

In this section we aim to test the robustness of our results to the introduction of transportation costs. We assume that exporting in a foreign country implies a unit transportation cost equal to $t \geq 0$. In the open economy the total profit of firm i writes:

$$\Pi_i^D = p_{i1}q_{i1} + p_{i2}q_{i2} - tq_{ij} - k_i\frac{\phi_i^2}{2} \tag{47}$$

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

$$q_{ijt}^D = \frac{2v_i^I - v_{-i}^I}{3b_j} + \frac{2t}{3a_ib_j}, \qquad i, -i, j \in \{1, 2\}, i \neq -i \tag{48}$$

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

9.1.1 The socially optimal level of investment:

Optimizing (**??**) with the profit function being replaced by (47) and the quantity formula by (48) the socially optimal level of innovation in country i becomes:

$$\phi_i^* = \frac{\alpha - t\frac{b_1+b_2}{2b_1b_2}}{\frac{9}{8}\frac{k_1k_2}{k_1+k_2} - (\alpha)} \frac{k_j}{k_1+k_2} \tag{49}$$

and the optimal level of innovation in the common market is

$$\phi_t^* = \phi_1^* + \phi_2^* = \frac{\alpha - t\frac{b_1+b_2}{2b_1b_2}}{\frac{9}{8}\frac{k_1k_2}{k_1+k_2} - (\alpha)}. \tag{50}$$

9.1.2 Full IPR protection (F regime)

Substituting the quantities (48) in the profit function firm i maximizes (47) with respect to ϕ_i, for a given level of ϕ_j, $i \neq j$. Profit maximization gives the reaction function:

$$\phi_i(\phi_j) = \frac{\alpha(1-\phi_j) - \frac{2b_i - b_j}{b_ib_j}t}{2.25k_i - 2\alpha} \tag{51}$$

We first notice that the slope of the reaction function remains negative: $\frac{\partial \phi_i(\phi_j)}{\partial \phi_j} < 0$. Quality levels, and thus investment levels, are strategic substitutes. 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 $t > 0$, 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).

Solving the system of first order conditions, we obtain:

$$\phi_i^F = \frac{1}{2}\frac{\alpha(1-\frac{\alpha}{3k_j})\frac{k_j}{k_1+k_2} - \frac{t}{k_1+k_2}(k_j(\frac{2}{b_j} - \frac{1}{b_i}) - \frac{4\alpha}{3b_j})}{\frac{9}{8}\frac{k_1k_2}{k_1+k_2} - \alpha(1 - \frac{\alpha}{3\frac{k_1+k_2}{2}})} \tag{52}$$

As in the benchmark case the level of quality chosen by firm i depends negatively on k_i and positively on k_j. More interestingly ϕ_i^F decreases with t if and only if:

$$\frac{b_j}{b_i} \leq 2 - \frac{4}{3}\frac{\alpha}{k_j} \tag{53}$$

Inequality (53) is easier to satisfy when k_j increases.

9.1.3 No IPR protection (N regime)

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

$$\phi_i(\phi_j) = \frac{\alpha(1+\phi_j) - \frac{2b_i - b_j}{b_i b_j}t}{4.5k_i - \alpha} \tag{54}$$

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

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

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:

$$\phi_i^N = \frac{\alpha \frac{k_j}{k_1+k_2} - \frac{t}{k_1+k_2}(k_j(\frac{2}{b_j} - \frac{1}{b_i}) - \frac{2}{3}\alpha(\frac{1}{b_j} - \frac{1}{b_i}))}{4.5\frac{k_1 k_2}{k_1+k_2} - \alpha} \tag{55}$$

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:

$$\frac{b_j}{b_i} \leq \frac{2(3k_j - \alpha)}{3k_j - 2\alpha} \tag{56}$$

Then, a decrease of the transportation cost increases the level of investment of country i if and only if country j is relatively large. Inequality (56) is easier to satisfy when k_j decreases.

We deduce that:

$$\phi^N = \phi_1^N + \phi_2^N = \frac{\alpha + \frac{t}{k_1+k_2}(k_1(\frac{1}{b_2} - \frac{2}{b_1}) + k_2(\frac{1}{b_1} - \frac{2}{b_2}))}{4.5\frac{k_1 k_2}{k_1+k_2} - \alpha}. \tag{57}$$

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

9.1.4 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 compete with 2 à la Cournot in country 2. At the second stage quantities are given by the Cournot levels in (48). At the first stage, profit maximization gives the reaction functions:

$$\phi_1(\phi_2) = \frac{(1+\phi_j)(2.25\alpha_1+\alpha_2) - \frac{2t}{b_2}}{4.5k_1 - (2.25\alpha_1+\alpha_2)} \quad (58)$$

$$\phi_2(\phi_1) = \frac{(1+\phi_1)\alpha_2 + \frac{t}{b_2}}{4.5k_2 - \alpha_2} \quad (59)$$

Once again, investments are strategic complements. That is, the slope of reaction function is positive for both firms: $\frac{\partial\phi_i(\phi_j)}{\partial\phi_j} > 0 \;\; i,j = 1,2 \; i \neq j$. Solving for the equilibrium we have:

$$\phi_1^P = \frac{(2.25\alpha_1+\alpha_2)k_2 - \frac{t}{b_2}(2k_2 - \frac{1}{2}\alpha_1 - \frac{2}{3}\alpha_2)}{4.5k_1k_2 - (2.25\alpha_1+\alpha_2)k_2 - \alpha_2 k_1} \quad (60)$$

$$\phi_2^P = \frac{\alpha_2 k_1 + \frac{t}{b_2}(2k_1 - \frac{1}{2}\alpha_1 - \frac{2}{3}\alpha_2)}{4.5k_1k_2 - (2.25\alpha_1+\alpha_2)k_2 - \alpha_2 k_1} \quad (61)$$

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

$$\phi^P = \phi_1^P + \phi_2^P = \frac{(\alpha_1\frac{2.25k_2}{k_1+k_2} + \alpha_2) - \frac{4t}{b_2(k_1+k_2)}(2k_2 - k_1)}{4.5\frac{k_1k_2}{k_1+k_2} - (\alpha_1\frac{2.25k_2}{k_1+k_2} + \alpha_2)} \quad (62)$$

This section shows that the results and the main intuitions are robust to the introduction of a variable exportation cost. In order to keep the analysis and the presentation simple we thus set $t = 0$ in the main text.

9.2 Imperfect enforcement in country 1

Until now, when considering the possibility for firm 2 to imitate, we have restricted the attention to the limit cases of perfect enforcement in country 1 (regime P) and no enforcement (regime N). However, country 1 could have some difficulties in fully enforcing patent protection and excluding firm 2 from the market. For instance, firm 2 could manage to sell illegally in country 1. We explore this possibility assuming that if firm 2 imitates, it manages to (illegally) sell only a limited quantity of the good. To make things interesting, we assume this quantity is higher than zero but lower than the unconstrained optimal quantity that firm 2 would choose to sell in country 1 (i.e. $q_{21}^o = \frac{2v_2 - v_1}{3b_2} = \frac{1+\phi_1+\phi_2}{3b_2}$). The higher is the capacity of enforcement of IPR of country 1, the smaller will be the quantity sold illegally. To fix ideas, we can assume that, for given qualities v_1 and v_2, firm 2 manage to sell at maximum $(1-f)q_{21}^o$, where $f \in [0,1]$ represents the quality of enforcement. If $f = 1$, we are in the former regime P and firm 2 cannot export in 1 ($q_{21}^P = 0$). If $f = 0$ there are no constraint to imports of imitated goods in country 1, as in regime N. Naturally, the optimal investment levels will be affected by perspective sales. The reaction functions under (P) become:

$$\begin{aligned}
\phi_1(\phi_2) &= \frac{\alpha_1 \frac{(2+f)^2}{4} + \alpha_2}{4.5k_i - \left(\alpha_1 \frac{(2+f)^2}{4} + \alpha_2\right)}(1+\phi_2) \\
\phi_2(\phi_1) &= \frac{\frac{(2-f(1+f))}{2}\alpha_1 + \alpha_2}{4.5k\Delta - \left(\frac{(2-f(1+f))}{2}\alpha_1 + \alpha_2\right)}(1+\phi_1)
\end{aligned} \tag{63}$$

Solving the system we find:

$$\phi_{1f}^P = \frac{\Delta\left(\frac{(2+f)^2}{4}\alpha_1 + \alpha_2\right)}{4.5k\Delta - \frac{2+f}{4}\alpha_1(f(\Delta-2) + 2(\Delta+1)) - \alpha_2(1+\Delta)}$$

$$\phi_{2f}^P = \frac{\left(\frac{f^2+f-2}{2}\alpha_1 + \alpha_2\right)}{4.5k\Delta - \frac{f+2}{4}\alpha_1(f(\Delta-2) + 2(\Delta+1)) - \alpha_2(1+\Delta)}$$

$$\phi_f^P = \frac{\frac{f+2}{4}\alpha_1(f(\Delta-2) + 2(\Delta+1)) + 4\alpha_2(\Delta+1)}{4.5k\Delta - \frac{f+2}{4}\alpha_1(f(\Delta-2) + 2(\Delta+1)) - \alpha_2(1+\Delta)}$$

It is easy to verify that when $f = 1$, $\phi_f^P = \phi^P$ and when $f = 0$, $\phi_f^P = \phi^N$. Moreover:

$$\frac{\partial \phi_f^P}{\partial f} = \frac{2.25k\alpha_1\Delta(2\Delta - 1 + f(\Delta-2))}{4.5k\Delta - \frac{f+2}{4}\alpha_1(f(\Delta-2) + 2(\Delta+1)) - \alpha_2(1+\Delta)} \geq 0$$

Then, the ϕ_f^P curve lies between ϕ^P and ϕ^N and it is the closest to ϕ^N the lowest is f. The same property holds for all curves (investment levels, profits, welfare, consumer surplus). Then, imperfect enforcement would correspond to an intermediate case between (N) and (P).

9.3 Imperfect imitation

Until now, we have assumed that innovation is cumulative and both firms can fully incorporate the innovation developed by the rival when imitating, i.e. $v_i^N = v_i^P = 1 + \phi_1 + \phi_2$. However, it can be reasonable to think that in some cases imitation is only partial and the imitating firm can only partially reproduce the innovation developed by the competitor. We explored this case assuming $v_i^N = v_i^P = 1 + \phi_i + g\phi_j$, with $0 \leq g \leq 1$. In this case, the reaction functions under (P) become:

$$\begin{aligned} \phi_1(\phi_2) &= \frac{2.25\alpha_1(1 + g\phi_2) + (2 - g)\alpha_2(1 + (2g - 1)\phi_2)}{4.5k_i - (2.25\alpha_1 + (2 - g)^2\alpha_2} \\ \phi_2(\phi_1) &= \frac{(2 - g)\alpha_2(1 + \phi_1(2g - 1))}{4.5k_2 - (2 - g)^2\alpha_2} \end{aligned}$$

And under (N):

$$\phi_i(\phi_j) = \frac{\alpha(2 - g)(1 + (2g - 1)\phi_2)}{4.5k_i - (2 - g)^2\alpha} \tag{64}$$

As the reaction function shows, for $g > 1/2$, the investment levels are strategic complements and the reaction functions are qualitatively similar to the ones in the base case. On the other hand, when g is very small, the public good effect of investment under imitation becomes negligible. Solving the system we obtain:

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

$$\begin{aligned} \phi_{ig}^N &= \frac{2(2 - g)\alpha(3k\Delta - 2(2 - g)(1 - g)\alpha)}{4\left(g^2 - 1\right)(g - 2)^2\alpha^2 + 6(g - 2)^2k(\Delta + 1)\alpha - 27k^2\Delta} \\ \phi_g^N &= \frac{2(2 - g)\alpha\left(3k\Delta - 2g^3\alpha + 4g^2\alpha + g(3k + 2\alpha) - 4\alpha\right)}{4\left(1 - g^2\right)(2 - g)^2\alpha^2 + 6(2 - g)^2k(\Delta + 1)\alpha - 27k^2\Delta} \end{aligned}$$

These expressions are significantly more complicated than in the base case. Then, the comparison, of investment levels, profit an welfare has been just studied by simulations. Naturally, when g is sufficiently close to 1, all the results are preserved. In the general case $0 < g < 1$, the main impact of imperfect imitation is to reduce the free-riding effect of imitation. Thne, innovation of firm 1 increases as well as the total level of innovation.

As a result, the profit of firm 2 tends to decrease while the profit of firm 1 and consumer welfare to increase. This does not affect the main qualitative results of our model, except that regimes (P) and (N) are preferred more often from the total welfare point of view. On the contrary, imitating becomes less attractive for firm 2, then imitation occurs less often.

Moreover, the relative quality of firm 1, which invests more, increases. Then its exports to country 2 are increased with respect to the base case. This is in line with the predictions of several empirical works that find that, when the imitation capacity is lower, the negative impact of weak IPR on imports is less pronounced (or disappears).

9.4 Extension 3: $v_i^P = v_i^N = 1 + max[\phi_1, \phi_2]$

Suppose now that in case of imitation, the quality of the good corresponds to the highest of the two, 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, there always exists an equilibrium where only firm 1 invests and the quality under (N) is:

$$\phi_1 = \frac{2\alpha}{9k_1 - 2\alpha}$$

While under (P):

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

These investment levels correspond exactly to the base case when $k_2 \to \infty$ (and then $\phi_2 \to 0$). Then, when the quality of the good depends on the maximal developed quality, at this equilibrium everything is as in our previous analysis for the case $\Delta \to \infty$.

This equilibrium might not be unique if Δ is small and γ large. In the latter case, another equilibrium may exists in which only firm 2 invests. However, this second Nash equilibrium seems less realistic, because it arises only for very small Δ and high γ. For these values of the parameter, it would be not clear that country 2 can be intended as a less developed one.

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:

$$\begin{aligned}\Pi_1^{I_1} &= \frac{k_1\alpha}{9k_1 - 2\alpha}\\ \Pi_2^{I_1} &= \frac{9k_1^2\alpha}{(9k_1 - 2(\alpha_1+\alpha_2))^2}\end{aligned}$$

Under Assumption 2 we have:

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

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

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

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

$$\begin{aligned}\Pi_1^{I_2} &= \frac{9\alpha k_2^2}{(9k_2 - 2\alpha)^2}\\ \Pi_2^{I_2} &= \frac{\alpha k_2}{9k_2 - 2\alpha}\end{aligned}$$

Which under Assumption 2 becomes:

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

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

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

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

For $1 \leq \Delta < 1 + \frac{2\sqrt{2}}{3} \simeq 1.94$, the second Nash equilibrium (firm 2 invests, firm 1 does not) can also arise.

Finally, if we consider a candidate equilibrium in which $\phi_1 = \phi_2$, firms maximize the expected profit:

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

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

Regime P:

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

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

The profits are:

$$\begin{aligned} \Pi_1^{I_1} &= \frac{k_1(9\alpha_1 + 4\alpha_2)}{36k_1 - 8\alpha_2 - 18\alpha_1} \\ \Pi_2^{I_1} &= \frac{36k_1^2\alpha_2}{(18k_1 - 9\alpha_1 - 4\alpha_2)^2} \end{aligned}$$

Under Assumption 2 we have:

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

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

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

The profits are:

$$\Pi_1^{I_2} = \frac{9k_2^2(4\alpha_2 + 9\alpha_1)}{4(9k_2 - 2\alpha_2)^2}$$
$$\Pi_2^{I_2} = \frac{k_2\left(9k_2\alpha_2 - 2\alpha_2^2\right)}{(9k_2 - 2\alpha_2)^2}$$

Under Assumption 2 and letting $\gamma = \frac{\alpha_2}{\alpha_1}$ (see (20)), we have:

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

Proceeding as above, we can verify that, under Assumption 2, 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 in which only firm 2 invests exists. 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 lager 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 than allowed to export in country 1 even under (P), then the conditions for having the second equilibrium to exist is ever more demanding. A necessary condition is $\gamma > 333/32 \simeq 10.4$ and $\Delta \leq \frac{\sqrt{128\gamma^2+396\gamma+243}+12\gamma+27}{12\gamma+162} \leq 1+\frac{2\sqrt{2}}{3} \simeq 1.94$.

9.5 Asymmetry in the initial quality levels

In our model, we have assumed that before investment the two firms have the same base quality, normalized to $v_1 = v_2 = 1$. However, in many situations it may be reasonable to assume that the quality of the two firms differ ex-ante (i.e. before investment). This can depend on the length of patent protection, which does not make the previous design available before new innovation takes place. To capture this issue, we assume that before investment the quality of firm 1 is $v_1 = 1$ and the quality of firm 2 is $v_2 = 1 - d$, where d represent the technological gap between the two good, depending on previous innovations still subject to patent protection. We also assume that, if imitation is allowed, this gap can be closed (the difference d can also be imitated) and everything is as in the base case.

However, 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 the for the optimal level of investment we obtain that the level of investment of firm 2 is:

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

and Firm 1 investment is $\phi_{1d}^F = \frac{6(1+d)\Delta - 4}{15\Delta - 8}$ if $\phi_{2d}^F > 0$ and $\phi_{1d}^F = 2(1+d)/5$ otherwise.

As the intuition suggests, ϕ_{1d}^F increases and ϕ_{2d}^F decreases in d. It is straightforward to verify that, for d sufficiently large (i.e. $d \geq \frac{27\Delta + 2(6+\Delta)(\alpha_2/\alpha_1)}{27\Delta + 4(32\Delta - 4)(\alpha_2/\alpha_1)}$) ϕ_{d2}^F becomes smaller than ϕ_2^P (see Equation (15)). Similarly, one can show that W_1^F is increasing in d while W_2^F is decreasing: when the developing country has an initial disadvantage, it is more likely to prefer not to enforce IPR.

9.6 Foreign market access construction

In the text we argue that market size can be proxied by GDP and we want to assess the impact of internal and external market sizes. As discussed in Section 4 and appendix 9.1, the existence of transportation costs is not altering the main insights of the model, but it interacts with the (relative) size of the foreign market in determining the quantitative impact of the IPR regime choice. We thus incorporate the role of transportation costs in our measure of the size of foreign demand. In order to take into account the foreign component, we need a measure to weight each potential destination market by their accessibility. In particular, F-ALPHA = $\sum_{j \neq i} GDP_j \hat{\phi}_{ij}$, where $\hat{\phi}_{ij}$ is a weight specific to the relationship between countries i and j. We use a trade gravity equation (see Head and Mayer, 2004 and Redding and Venables, 2004) to obtain these weights for each year of our sample. The gravity equation relates bilateral trade flows to variables that are supposed to deter (e.g. distance among partners) or favor (e.g. common language) economic exchanges. Of course, these are not the only components of trade costs. There are also variables specific to the exporter or the importer, like institutional quality or landlocked status. To focus on the bilateral component, we include exporter and importer fixed effects to control for these country-specific variables. The bilateral variables that we consider are bilateral distance (in log), and dummies equaling one if the partners shares a common language or border and if one of the countries was a colonizer of the other. All these explanatory variables are available from the CEPII Gravity Dataset. Bilateral trade is from BACI-COMTRADE which provides detailed information on trade flows for manufacturing, agricultural products and raw materials. We concentrate our analysis on the manufacturing trade, as most of empirical studies on market access and innovation. As expected, the coefficient for distance is negative and the coefficients for common language, border and colonial past are positive (regressions available on request). Using the coefficients of the bilateral variables we predict the trade costs for each pair of partners.

9.7 Inside the frontier innovation

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

9.8 Closed economy

In the case of a closed economy, demand in country $i = 1, 2$ is:

$$p_i = a_i(v_i - b_i q_i) \tag{65}$$

where v_i represents the quality and q_i the quantity of good i. There is a monopoly in each country. The firms maximize their profit with respect to the level of investment in

R&D, ϕ_i, and the quantity, q_i $(i = 1, 2)$:

$$\Pi_i = p_i q_i - k_i \frac{\phi_i^2}{2}. \tag{66}$$

Substituting p_i defined equation (65), the profit function is $\Pi_i = a_i(1+\phi_i - b_i q_i)q_i - k_i \frac{\phi_i^2}{2}$. It is straightforward to check that under assumption 1, the profit 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 quantity:

$$q_i^M = \frac{1+\phi_i}{2b_i}. \tag{67}$$

and the investment level:

$$\phi_i^M = \frac{\alpha_i}{2k_i - \alpha_i} \tag{68}$$

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. Let $S_i^M = \frac{\alpha_i}{8}(1+\phi_i)^2$ be the consumer surplus $S_i = \frac{1}{2}(av_i - P_i(q_i))q_i$ evaluated at $q_i^M = \frac{1+\phi_i}{2b_i}$. Similarly let $\Pi_i^M = \frac{\alpha_i}{4}(1+\phi_i)^2 - k_i\frac{\phi_i^2}{2}$ be the profit of the firm (66) evaluated at $q_i^M = \frac{1+\phi_i}{2b_i}$. 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). Maximizing $W_i^M = S_i^M + \Pi_i^M$ with respect to ϕ_i we obtain:

$$\phi_i^{M*} = \frac{\alpha_i}{\frac{4}{3}k_i - \alpha_i} \tag{69}$$

Comparing equations (68) and (69), 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.

Comparison with autarchy

Let $k_2 = \Delta k_1$, $\delta \geq 1$ and $\alpha_2 = \gamma\alpha_1$, $\gamma > 0$. 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.

Notice that, due to the normalization in Assumption 1, 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 α). 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 $\Delta \to \infty$ (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 $\Delta \to 1$, 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 $\phi_2^P \leq \phi_2^M$).