

Would global patent protection be too weak without international coordination?*

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Abstract

Would global patent protection be too weak without international coordination? Would it be too strong with the international coordination mandated by the TRIPS agreement (Agreement on Trade-Related Aspects of Intellectual Property Rights)? I try to answer these questions using a model of patent-setting game between governments. I introduce firm-biased government preferences and trade barriers, and then make use of the estimates of the firm-bias parameter from the political economy literature to proxy for the degree of governments' firm-bias. Then I calculate the range of trade barriers that is sufficient to give rise to under-protection of patents in the global system without international policy coordination in intellectual property rights (IPR) protection. I make the judgment that the true trade barrier between countries very likely falls within this range of under-protection. Therefore, I conclude that there probably would be under-protection of patent rights without international policy coordination. Confronting the model with data on market sizes and patent counts, I find that requiring all countries to harmonize their patent standards with the equilibrium standard of the most innovative country quite likely leads to global over-protection of patent rights. Therefore, it is quite likely that global patent protection is too strong if TRIPS is fully enforced.

Keywords: intellectual property rights, patents, TRIPS, harmonization

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1 Introduction

The global intellectual property rights (IPR) protection system was given a boost by the implementation of the TRIPS agreement (Agreement on Trade-Related Aspects of Intellectual Property Rights), which started a gradual process of IPR harmonization in 1995. This agreement effectively requires the strengthening of patent protection of many countries, and forces the world IPR protection policies towards harmonization (albeit a partial one). There have been nothing nearly as powerful as TRIPS in its ability to coordinate international IPR protection, not least because of the large number of countries involved (it is under the auspices of the WTO) and its ability to enforce rulings due to the credibility of the threat of punishment through trade retaliation. Given the tremendous repercussions of such a coordinated increase in the strengths of IPR protection, it is fair to ask whether TRIPS is really a solution to a global coordination problem. It is clear that TRIPS has distributive effect between countries.¹ However, the more important question is whether global IPR protection was too weak before TRIPS. If it was, then TRIPS can potentially be globally welfare-improving and therefore potentially make all countries better off. For example, if less developed countries (LDCs) lose from strengthening of their IPR and developed countries (DCs) gain from it, but the latter's gains outweigh the former's losses, then it can be mutually beneficial for the LDCs to accept (partial) harmonization of IPR standards with the DCs in exchange for the DCs' opening their markets for labor-intensive manufacturing goods or agricultural products from the LDCs. However, if global patent protection was already too strong before TRIPS, then no such synergy exists between negotiations on trade-related IPR and other issues of global trade.

There is no doubt that some countries attempted to coordinate their IPR policies somewhat even before TRIPS, but empirical studies have shown that even as late as 1990, market sizes and innovative capabilities significantly affected variation in the strengths of patent protection across countries, as would be expected of a world where each country

¹McCalman (2001) has shown that the US was by far the largest beneficiary, followed by Germany and France as distant second and third beneficiaries. On the other hand, the greatest loser was Canada, followed by Brazil and UK.

sets its own optimal IPR standard.² So, I start with the working assumption that the world was in a non-cooperative equilibrium before TRIPS, and then ask, Would global patent protection be too weak when left to individual governments to decide their own level of protection?

To answer this question, we need to (a) have a theory that explains how the global system of patent protection was determined in a non-cooperative equilibrium; (b) have a theory that explains how the optimal global system of patent protection should be; and (c) develop a sufficient condition for global under-protection (or over-protection) of IPR. In order to answer (c), we need to explain how a global system of patent protection affects incentives to innovate and how it creates distortions (deadweight losses). Therefore, we need to answer (a) and (b) first. To do so, I modify and extend a model by Grossman and Lai (2004). In Section 2, I shall concisely re-state their theory. Then, I extend the model so as to more realistically evaluate whether there would be under-protection of IPR in non-cooperative equilibrium.

A second and related question I ask is, Would global patent protection be too strong with international coordination mandated by TRIPS? To answer this question, we need to determine what TRIPS aims to achieve in the context of our model. Adopting the views of Reichman (1995) and Lai and Qiu (2003), I make the assumption that TRIPS requires all countries in the world to set their IPR standards equal to that of the most protective country in Nash equilibrium. The model described in the last paragraph would help us to answer this second question.

In the basic model of Grossman and Lai (2004), countries play a Nash game in setting the strengths of patent protection. The best response function of a country's government is obtained by setting the strength of patent protection that equates the marginal costs (deadweight loss due to longer duration of monopoly pricing) and marginal benefits (increased incentives of innovation) of extending protection, given the strengths of protection of other countries. Each country confers positive externalities to foreign countries as it extends patent protection, because it increases profits of foreign firms in the home market, and increases consumer surplus of foreign consumers due to induced innovations. As a

²See, for example, Ginarte and Park (1997) and Maskus (2000a).

result, there is under-protection of patent rights in Nash equilibrium relative to the global optimum. In fact, the degree of under-protection in Nash equilibrium increases with the number of independent decision-makers in the patent-setting game.

However, two factors prevents us from directly applying Grossman and Lai's (2004) basic model to answer whether global patent protection would be too weak without international coordination. First, as discussed in the political economy literature, governments may put extra weight on profits as opposed to consumer surplus in their objective functions (e.g. due to firm lobbying). I shall call this firm-biased preferences of governments. When governments put more weight on profits, the marginal cost of patent protection decreases since deadweight loss is smaller. Therefore, patent protection in Nash equilibrium is stronger. Second is the existence of trade barriers. As recent empirical trade literature documents, only a small fraction of firms export to foreign markets. Moreover, the firms that do export have to bear variable trade costs, which include transportation cost and import tariffs. When only a fraction of domestic firms would enter a foreign market, and when there are transportation cost and other trade costs, the positive international externalities of patent protection is diminished. Both firm-bias and trade barriers tend to diminish the degree of under-protection in Nash equilibrium relative to the global optimum. If these forces are strong enough, there may even be over-protection of patents in Nash equilibrium. Therefore, whether or not there is under-protection of patents in the non-cooperative equilibrium is an empirical question. In this paper, I incorporate these two features in an extension of the basic Grossman and Lai (2004) model and derive a sufficient condition for under-protection of patent in the global economy. I then calibrate the model using the firm-bias parameter estimated from the empirical literature and then find out how small the trade barriers have to be in order for there to be under-protection of patents in Nash equilibrium.

In the basic model, we can find a functional relationship between the global strength of patent protection and global welfare. The same strength of global patent protection creates the same amount of total deadweight losses (what I call static losses) and aggregate flow of new differentiated goods (what I call dynamic gains) in each period. As long as the global strength of patent protection is the same, global welfare is the same, regardless

of the combination of individual countries' strengths of patent protection. Therefore, the global optimum is a continuum of combinations of national strengths of patent protection that maximize global welfare. However, this will not be true in the extended model. In the more general model with trade barriers, there does not exist a scalar measure of the global strength of patent protection such that there is a functional relationship between the global strength of protection and global welfare. Despite this problem, I am able to calculate a sufficient condition under which, starting from Nash equilibrium, global welfare must increase with increases in the strengths of protection in all countries. When this condition is satisfied, we can conclude that there is under-protection in global IPR protection.

The key features of the extended model are: 1. There is only one single combination, not a continuum, of national strengths of patent protection that maximizes global welfare. 2. Externalities still exist, but their magnitude decreases with trade barriers. Therefore, the degree of under-protection decreases with trade barriers. 3. The degree of under-protection decreases with the firm-bias of governments. Based on the estimates of the firm-bias parameter from the political economy literature, and my judgment of the plausible magnitude of trade barrier, I conclude that under-protection of global patent protection in the non-cooperative equilibrium is very likely. This answers my first question.

One interesting result arising from the basic model is that requiring all other countries to increase their equilibrium patent standards so as to harmonize with that of the most protective country is never over-protective from the global welfare point view, and thus it is always welfare-improving. In the extended model, whether or not such a harmonization scheme is over-protective depends on trade barriers, the degree of firm-bias and the distribution of innovative capability and distribution of market size among the countries in the world. Confronting the extended model using data and parameter estimates from the literature, I find that under such a harmonization scheme, the sufficient condition for under-protection is far from satisfied. If such a scheme captures what the TRIPS aims to achieve, then fully enforcing TRIPS would probably result in over-protection of patent rights in the global economy. This answers my second question. Taken together, the answers to the two questions indicate that though some international coordination of IPR

protection is needed, the coordination scheme mandated by the TRIPS may be too strong a dose of medicine.

In section 2, I recap the essence of the basic model of Grossman and Lai (2004). In section 3, I extend the basic model to incorporate firm-bias and trade barriers. Then, I proceed to answer the two questions posed above. Finally, I conclude in section 4.

2 A basic theory of international protection of IPR

The theory described in this section basically draws from Grossman and Lai (2004).

2.1 Noncooperative Patent Protection

In this section, I study the national incentives for protection of intellectual property in a world economy with imitation and trade. I derive the Nash equilibria of a game in which two countries set their patent policies simultaneously and noncooperatively. The countries are distinguished by their wage rates, their market sizes, and their stocks of human capital. The last of these proxies for their different capacities for R&D. We shall term the countries “North” and “South,” in keeping with our desire to understand the tensions that surrounded the tightening of intellectual property rights (IPR) protection in the developing countries in the last decade. Keith E. Maskus (2000a, ch.3) has documented an increase in innovative activity in poor and middle-income countries such as Brazil, Korea, and China, so our model of relations between trading partners with positive but different abilities to conduct R&D may be apt for studying the incentives for IPR protection in a world of trade between such nations and the developed economies.³ But our model may apply more broadly to relations between any groups of countries that have different wages and different capacities for research. Such differences exist, albeit to a lesser extent than between North and South, in the comparison of countries in Northern and Southern Europe, or the comparison of the United States and Canada. We do not

³He also shows the extent to which patent applications in countries like Mexico, Brazil, Korea, Malaysia, Indonesia and Singapore are dominated by foreign firms, a feature of the data that figures in our analysis.

mean the labels North and South to rule out the application of our analysis to these other sorts of relationships.

2.1.1 The Global IPR Regime

Consumers in the two countries share identical preferences. In each country, the representative consumer maximizes the intertemporal utility function. The instantaneous utility of a consumer in country j is given by

$$u_j(z) = y_j(z) + \int_0^{n_S(z)+n_N(z)} h[x_j(i, z)] di, \quad (1)$$

where $y_j(z)$ is consumption of the homogeneous good by a typical resident of country j at time z , $x_j(i, z)$ is consumption of the i^{th} differentiated product by a resident of country j at time z , and $n_j(z)$ is the number of differentiated varieties previously invented in country j that remain economically viable at time z . There are M_N consumers in the North and M_S consumers in the South. While we do not place any restrictions on the relative sizes of the two markets at this juncture, we shall be most interested in the case where $M_N > M_S$.⁴ It does not matter for our analysis whether consumers can borrow and lend internationally or not.

In country j , it takes a_j units of labor to produce one unit of the homogeneous good or to produce one unit of any variety of the differentiated product. New goods are invented in each region according to $\phi_j = F(H_j, L_{Rj}/a_j) = A(L_{Rj}/a_j)^b H_j^{1-b}$, where H_j is an input whose quantity determines the innovative capability of country j , L_{Rj} is the labor devoted to R&D there. We assume that $a_N < a_S$, which means that labor is uniformly more productive in the North than in the South. We also assume that the numeraire good is produced in positive quantities in both countries, so that $w_j = 1/a_j$ for $j = S, N$, and hence $w_N/w_S = a_S/a_N > 1$. Define $\bar{T} = (1 - e^{-\rho\bar{\tau}})/\rho$, where $\bar{\tau}$ is the product life of a differentiated good.

We now describe the IPR regime. In each country, there is *national treatment* in the granting of patent rights. Under national treatment, the government of country j affords

⁴We remind the reader that market size is meant to capture not the population of a country, but rather the scale of its demand for innovative products.

the same protection $\Omega_j = \omega_j T_j$ to all inventors of differentiated products regardless of their national origins, where ω_j is the probability that a patent is enforced in country j (or the fraction of country j 's market where a patent is enforced) at any moment in time, $T_j = (1 - e^{-\rho\tau_j})/\rho$, and τ_j is the length of the patents granted by country j . In other words, we assume that foreign firms and domestic firms have equal standing in applying for patents in any country and that all patents are subject to the same enforcement provisions. National treatment is required by TRIPS and it characterized the laws that were in place in most countries even before this agreement.⁵ In our model, a patent is an exclusive right to make, sell, use, or import a product for a fixed period of time (see Maskus, 2000a, p.36). This means that, when good i is under patent protection in country j , no firm other than the patent holder or one designated by it may legally produce the good in country j for domestic sale or for export, nor may the good be legally imported into country j from an unauthorized producer outside the country. We also rule out parallel imports — unauthorized imports of good i that were produced by the patent holder or its designee, but that were sold to a third party outside country j .⁶ When parallel imports are prevented, patent holders can practice price discrimination across national markets.

We solve the Nash game in which the governments set their patent policies once-and-for-all at time 0. These patents apply only to goods invented after time 0; goods invented beforehand continue to receive the protections afforded at their times of invention. So long

⁵National treatment is required by the Paris Convention for the Protection of Industrial Property, to which 127 countries subscribed by the end of 1994 and 164 countries subscribe today (see <http://www.wipo.org/treaties/ip/paris/index.html>). There were, however, allegations from firms in the United States and elsewhere that prior to the signing of TRIPS in 1994, nondiscriminatory laws did not always mean nondiscriminatory practice. See Suzanne Scotchmer (2004) for an analysis of the incentives that countries have to apply national treatment in the absence of an enforceable agreement.

⁶The treatment of parallel imports under TRIPs remains a matter of legal controversy. Countries continue to differ in their rules for territorial exhaustion of IPRs. Some countries, like Australia and Japan, practice international exhaustion, whereby the restrictive rights granted by a patent end with the first sale of the good anywhere in the world. Other countries or regions, like the United States and the European Union, practice national or regional exhaustion, whereby patent rights end only with the first sale within the country or region. Under such rules, patent holders can prevent parallel trade. See Maskus (2000b) for further discussion.

as the governments cannot remove protections that were previously granted, the economy has no state variables that bear on its choice of optimal patent policies at a given moment in time. This means that the Nash equilibrium in once-and-for-all patents is also a subgame perfect equilibrium in the infinitely repeated game in which the governments can change their patent policies periodically, or even continuously. Of course, the repeated game may have other equilibria in which the governments base their current policies on the history of prior actions. We do not investigate such equilibria with tacit cooperation here, but rather postpone our discussion of cooperation until a later section.

Let us describe, for given patent strengths Ω_N and Ω_S , the life cycle of a typical differentiated product. During an initial phase after the product is introduced, the inventor holds an active patent in both countries which is only partially enforced. The patent holder earns an expected flow of profits of $\omega_N M_N \pi$ from sales in the Northern market and an expected flow of profits of $\omega_S M_S \pi$ from sales in the Southern market, where π is earnings per consumer for a monopoly selling a typical brand. Notice that monopoly profits per consumer are the same for sales in both markets, because consumers share identical preferences. Also, they do not depend on where a good was invented or where it is produced, because the productivity gap between the countries exactly offsets the wage differential. Each Northern consumer realizes a flow of expected surplus of $\omega_N C_m + (1 - \omega_N) C_c$ from his purchases of the good, where C_m is the surplus that a consumer derives from purchases of a good produced at a cost of $w_j a_j = 1$ and sold at the monopoly price p_m and C_c is the surplus he derives from a product sold for the competitive price of $p_c = 1$. Similarly, a Southern consumer realizes an expected flow of consumer surplus of $\omega_S C_m + (1 - \omega_S) C_c$ from his purchases of the good.

After a while, the patent will expire in one country. For concreteness, let's say that this happens first in the South. Then the good will be legally imitated by competitive firms producing there, for sales in the local (Southern) market. The imitators will not, however, be able to sell the good legally in the North, because the live patent there, if enforced, affords protection from such infringing imports. When the patent expires in the South, the price of the good falls permanently to $w_S a_S = 1$, and the original inventor ceases to realize profits in that market. The flow of consumer surplus in the South rises

to $M_S C_c$.

Eventually, the inventor's patent expires in the North. Then the Northern market can be served completely by competitive firms producing in either location. At this time, the price of the good in the North falls to $p_c = 1$ and households there begin to enjoy the higher flow of consumer surplus $M_N C_c$. The original inventor loses his remaining source of monopoly income. Finally, after a period of length $\bar{\tau}$ has elapsed from the moment of invention, the good becomes obsolete and all flows of consumer surplus cease.

2.1.2 The Best Response Functions

Consider the choice of patent policies Ω_N and Ω_S that will take effect at time 0 and apply to goods invented thereafter. The expressions for the aggregate welfare in country i , discounted to time 0, is given by

$$\begin{aligned} W_i(0) &= \Lambda_{i0} + \frac{w_i L_i}{\rho} + \frac{r_i H_i}{\rho} + \frac{M_i(\phi_S + \phi_N)}{\rho} [\Omega_i C_m + (\bar{T} - \Omega_i) C_c] \\ &= \Lambda_{i0} + \frac{w_i(L_i - L_{Ri})}{\rho} + \frac{M_i(\phi_S + \phi_N)}{\rho} [\Omega_i C_m + (\bar{T} - \Omega_i) C_c] \\ &\quad + \frac{\phi_i}{\rho} \pi (M_S \Omega_S + M_N \Omega_N), \quad \text{for } i = S, N, \end{aligned} \quad (2)$$

where Λ_{i0} is the fixed amount of discounted surplus that consumers in country i derive from goods that were invented before time 0. The second equality arises from the fact that there is zero profit for each firm, so that $r_i H_i + w_i L_{Ri} = \phi_i v = \phi_i \pi (M_S \Omega_S + M_N \Omega_N)$, where $v = (M_S \Omega_S + M_N \Omega_N) \pi$ is the value of a new patent.

We are now ready to derive the best response functions for the two governments. The best response expresses the strength of patent protection that maximizes a country's aggregate welfare as a function of the given patent policy of its trading partner. Consider the choice of Ω_S by the government of the South. This country bears two costs from strengthening its patent protection slightly. First, it expands the fraction of goods previously invented in the South on which the country suffers a static deadweight loss of $M_S(C_c - C_m - \pi)$. Second, it augments the fraction of goods previously invented in the North on which its consumers realize surplus of $M_S C_m$ instead of $M_S C_c$. Notice that the

profits earned by Northern producers in the South are not an offset to this latter marginal cost, because they accrue to patent holders in the North. The marginal benefit that comes to the South from strengthening its patent protection reflects the increased incentive that Northern and Southern firms have to engage in R&D. If the welfare-maximizing Ω_S is positive and less than \bar{T} , then the marginal benefit *per consumer* of increasing Ω_S must match the marginal cost, which implies

$$\phi_S(C_c - C_m - \pi) + \phi_N(C_c - C_m) = \frac{\gamma_S\phi_S + \gamma_N\phi_N}{v} M_S\pi [C_m\Omega_S + C_c(\bar{T} - \Omega_S)], \quad (3)$$

where γ_j is the responsiveness of innovation in region j to changes in the value of a patent (in elasticity form), i.e. $\frac{\partial\phi_j}{\partial v} = \gamma_j \frac{\phi_j}{v}$.

Similarly, in the North, the marginal benefit of strengthening patent protection must match the marginal cost at any interior point on the best response curve. The marginal cost in the North is different from that in the South, because the North's national income includes the profits earned by Northern patent holders but not those earned by Southern patent holders. The marginal benefit differs too, because the effectiveness of patent policy as a tool for promoting innovation varies according to the importance of a country's market in the aggregate profits of potential innovators and because the surplus from a typical product over its lifetime depends upon a country's patent regime. The condition for the best response of the North, analogous to (3) above, is

$$\phi_S(C_c - C_m) + \phi_N(C_c - C_m - \pi) = \frac{\gamma_S\phi_S + \gamma_N\phi_N}{v} M_N\pi [C_m\Omega_N + C_c(\bar{T} - \Omega_N)]. \quad (4)$$

Noting that $\gamma_S = \gamma_N = \gamma$,⁷ the two best response functions can be written similarly as

$$C_c - C_m - \mu_i\pi = \gamma \frac{M_i\Omega_i}{M_S\Omega_S + M_N\Omega_N} \left[C_m + C_c \left(\frac{\bar{T} - \Omega_i}{\Omega_i} \right) \right] \quad \text{for } i = S, N, \quad (5)$$

⁷The fact that the two supply elasticities γ_S and γ_N are equal despite the differences in human capital endowments, in employment, and in labor productivity is a property of the Cobb-Douglas research technology. It follows from the observation that

$$\gamma_i = \frac{b}{(1-b)} \quad \text{for all } i$$

where $\mu_i = \phi_i/(\phi_S + \phi_N)$ is the share of world innovation that takes place in country i . Moreover, $\mu_i = H_i/(H_S + H_N)$ for this research technology. Thus, both μ_i and γ are independent of the patent policies in the Cobb-Douglas case. It follows from (5) that the best response functions are linear and downward sloping in this case, and that the best response function for the South is steeper than that for the North, when the two are drawn in (Ω_S, Ω_N) space.

Thus, the patent policies of the two countries are strategic substitutes. To understand the strategic interdependence between the governments in choosing their policies, consider the choice of patent protection by the South. Suppose the North were to strengthen its patent protection; i.e., to increase Ω_N . This would shrink the fraction of total discounted profits that an innovator earns in the South and so, *ceteris paribus*, reduce the responsiveness of global innovation to patent policy in the South. Moreover, the increase in Ω_N would draw labor into R&D in the North and South. The South would find that its market is relatively less important to potential innovators. For this reason, the marginal benefit to the South of strengthening its patent protection would fall and so the government would respond to the increase in Ω_N with a reduction in patent length or an easing of enforcement.

It is easy to show using (5) that the best response curve for the South must have a slope that is everywhere greater in absolute value than M_S/M_N , while the best response curve for the North must have a slope that is everywhere smaller in absolute value than M_S/M_N .⁸ It follows that the curve for the South must be steeper than that for the North at any point of intersection. This guarantees uniqueness of the Nash equilibrium and ensures stability of the policy setting game.

We summarize the most important findings in this section as follows.

⁸We have not discussed the shape of the best response functions where they hit the axes or where the constraint that $\Omega_i \leq \bar{T}$ begins to bind. The best-response curve of the South becomes vertical if it hits the vertical axis at a point below $\Omega_N = \bar{T}$. It also becomes vertical if the South's best response is \bar{T} for some positive value of Ω_N . Similarly, the best-response curve for the North becomes horizontal if either it hits the horizontal axis before $\Omega_S = \bar{T}$ or if the North's best response is \bar{T} for some positive value of Ω_S . Thus, the best response curve for the South must be steeper than that for the North at any point of intersection, even if these additional segments of the best response functions are taken into account.

Proposition 1 *Let the research technology be $\phi_j = A(L_{Rj}/a_j)^b H_j^{1-b}$ in country i , for $i = S, N$. Since the two patent policies are strategic substitutes in both countries, there exists a unique and stable Nash equilibrium of the policy setting game.*

2.2 International Patent Agreements

In this section, we study international patent agreements.⁹ We begin by characterizing the combinations of patent policies that are jointly efficient for the two countries.¹⁰ Then we compare the Nash equilibrium outcomes with the efficient policies, to identify changes in the patent regime that ought to be effected by an international treaty. Finally, we address the issue of policy harmonization. By that point, we will have seen that harmonization is neither necessary nor sufficient for global efficiency.

2.2.1 Efficient Patent Regimes

We shall begin by showing that the sum of the welfare levels of the two countries depends only on a measure Q of the *overall* protection afforded by the international patent system. This means that the same aggregate world welfare level can be achieved with different combinations of Ω_S and Ω_N that imply the same overall level of protection. One particular level of Q —call it Q^* —maximizes the sum of the countries' welfare levels. For a wide range of distributions of world welfare, efficiency is achieved by setting the individual patent policies so that the overall index of patent protection is Q^* .

In particular, let $Q = M_S\Omega_S + M_N\Omega_N$. This measure of global patent protection weighs the degree of patent protection in each country by the size of the country's market. A firm that earns a flow of expected profits of $\omega_S M_S \pi$ for a period of length τ_S in the

⁹See also McCalman (2002), who discusses globally efficient patent policies in his two-country extension of the Nordhaus (1969) model. Lai and Qiu (2003) consider whether the joint welfare of the two countries would be increased if the South were to extend its patents so as to be equal in length to those chosen by the North in a Nash equilibrium.

¹⁰Ours is a constrained efficiency, because we assume that innovation must be done privately and that patents are the only policies available to encourage R&D. We do not, for example, allow the governments to introduce R&D subsidies, which if feasible, might allow them to achieve a given rate of innovation with weaker patents and less deadweight loss.

South and a flow of expected profits of $\omega_N M_N \pi$ for a period of τ_N in the North earns a total discounted sum of expected profits equal to $Q\pi$. Thus, Q governs the allocation of resources to R&D in each country, regardless of the particular combination of patent policies in the separate countries.

Consider the choice of patent policies Ω_N and Ω_S that will take effect at time 0 and apply to goods invented thereafter. Summing the welfare expressions in (2) for $i = S$ and $i = N$, we find that

$$\begin{aligned} \rho [W_S(0) + W_N(0)] &= \rho (\Lambda_{S0} + \Lambda_{N0}) + w_S(L_S - L_{RS}) + w_N(L_N - L_{RN}) \\ &\quad + (M_S + M_N) \bar{T}(\phi_S + \phi_N) C_c - Q(\phi_S + \phi_N)(C_c - C_m - \pi) \end{aligned} \quad (6)$$

Since $v_S = v_N = \pi Q$, L_{RS} and L_{RN} are functions of Q .¹¹ The same is true of ϕ_S and ϕ_N . It follows that different combinations of Ω_S and Ω_N that yield the same value of Q also yield the same level of aggregate world welfare.¹²

If international transfer payments are feasible, then a globally efficient patent regime must have $M_S \Omega_S + M_N \Omega_N = Q^*$, where Q^* is the value of Q that maximizes the right-hand side of (6).¹³ Notice that a range of efficient outcomes can be achieved without the need for any international transfers. By appropriate choice of Ω_N and Ω_S , the countries can be given any welfare levels on the efficiency frontier between that which they would achieve if $\Omega_S = 0$ and $\Omega_N = Q^*/M_N$ and that which they would achieve if $\Omega_S = Q^*/M_S$ and $\Omega_N = 0$.¹⁴

¹¹In country i , the allocation of labor to research is determined by

$$\pi Q F_L(L_{Ri}/a_i, H_i) = 1/a_i.$$

¹²This result is anticipated by a similar one in McCalman (2002), who studied efficient patent agreements in a partial equilibrium model of cost-reducing innovation by a single, global monopolist.

¹³The first-order condition for maximizing $\rho[W_S(0) + W_N(0)]$ implies

$$C_c - C_m - \pi = \gamma \left\{ C_m + C_c \left[\frac{(M_S + M_N) \bar{T} - Q^*}{Q^*} \right] \right\}.$$

The second-order condition is satisfied at $Q = Q^*$.

¹⁴This statement ignores the ceiling on patent lengths imposed by the finite economic life of differentiated products. A more precise statement is that a range of distributions of maximal world welfare can be

Although aggregate world welfare does not vary with the national policies ω_i and τ_i as long as $M_S\Omega_S + M_N\Omega_N = Q^*$, the countries fare differently under the alternative combinations of policies that can be used to achieve global efficiency unless compensating transfers take place. In particular, the welfare of the North increases and that of the South decreases as Ω_S is increased and Ω_N is decreased in such a way as to keep the weighted sum constant. It follows that, absent any international transfer payments, the countries have a strong conflict of interest over the terms of an international patent agreement.

2.2.2 Pareto-Improving Patent Agreements

How do the efficient combinations of patent policies compare to the policies that emerge in a noncooperative equilibrium? The answer to this question — which informs us about the likely features of a negotiated patent agreement — is illustrated in Figure 1. The figure depicts the best response functions and the efficient policy combinations on the same diagram.

<Figure 1 about here>

In the figure, the efficient policy combinations are depicted by the line QQ .¹⁵ We show this line being situated to the right of the SS curve and above the NN curve, which is a general feature of our model. The reasons are clear. Starting from a point on the South's best response function, a marginal strengthening of IPR protection in the South increases world welfare. Such a change in Southern policies has only a second-order effect on welfare in the South, but it conveys two positive externalities to the North. First, it provides extra monopoly profits to Northern innovators, which contributes to aggregate income there. Second, it enhances the incentives for R&D, inducing an increase in both

achieved by varying Ω_S between $\Omega_S = \max\{0, (Q^* - M_N\bar{T})/M_S\}$ and $\min\{Q^*/M_S, \bar{T}\}$ while varying Ω_N between $\Omega_N = \min\{Q^*/M_N, \bar{T}\}$ and $\max\{0, (Q^* - M_S\bar{T})/M_N\}$ in such a way that $M_S\Omega_S + M_N\Omega_N = Q^*$.

¹⁵If international transfer payments are infeasible, the set of Pareto efficient policy combinations includes the segment of the vertical axis above its intersection with QQ and extending as far as the point $(0, \bar{T})$ and the segment of the horizontal axis to the right of its intersection with QQ and extending to $(\bar{T}, 0)$.

ϕ_S and ϕ_N . The extra product diversity that results from this R&D creates additional surplus for Northern consumers.

By the same token, a marginal increase in the strength of Northern patent protection from a point along NN increases world welfare. Such a change in policy enhances profit income for Southern firms and encourages additional innovation in both countries. It follows, of course, that the QQ line must lie outside the Nash equilibrium. We record our finding in

Proposition 2 *Let (Ω_S, Ω_N) be an interior equilibrium in the noncooperative policy game and let (Ω_S^*, Ω_N^*) be any efficient combination of patent policies. Then $M_S\Omega_S^* + M_N\Omega_N^* > M_S\Omega_S + M_N\Omega_N$.*

The proposition implies that, starting from any interior Nash equilibrium, an efficient patent treaty must strengthen patent protection in at least one country. It also implies that the treaty will strengthen global incentives for R&D and induce more rapid innovation in both countries.

2.3 Patent Policy with Many Countries

In this section, we extend our analysis to a trading world with many countries. Our main finding is that adding countries exacerbates the free-rider problem that plagues the noncooperative policy equilibrium. Small countries are inclined to allow others to provide the incentives for innovation so as to avoid the deadweight losses in their home markets. In the limit, as the number of countries grows large and each one is small in relation to the world economy, the unique Nash equilibrium has universal patents of strength zero. Then, a patent treaty is critical for creating incentives for private innovation.

We assume that there are J countries, and that country i has market size M_i , human capital endowment H_i , and labor productivity $1/a_i$. The research technology in country i is $\phi_i = F(H_i, L_{Ri}/a_i) = A(L_{Ri}/a_i)^b H_i^{1-b}$. All consumers share the preferences given in (1).

Suppose that there is no cooperation between nations in setting their patent policies. In country i , either $\Omega_i = 0$ and the marginal cost of providing the first bit of patent protection exceeds the marginal benefit, $\Omega_i = \bar{T}$ and the marginal benefit of providing the last bit of patent protection exceeds the marginal cost, or $0 < \Omega_i < \bar{T}$ and the marginal benefit of strengthening patent protection equals the marginal cost. Equality between marginal benefit and marginal cost implies

$$C_c - C_m - \mu_i \pi = \frac{M_i}{Q} \gamma [\Omega_i C_m + C_c (\bar{T} - \Omega_i)] , \quad (7)$$

where $Q = \sum_j M_j \Omega_j$ measures the strength of global patent protection in the Nash equilibrium.

Observe first that as $\mu_i \rightarrow 0$, the left-hand side of (7) approaches $C_c - C_m$; a small country captures virtually none of the monopoly profits from innovative products, so the marginal cost of a patent per consumer and product is the difference between the competitive and monopoly levels of consumer surplus. But as $M_i \rightarrow 0$, the right-hand side of (7) approaches zero, because a small country provides innovators with virtually none of their global profits and so worldwide innovation is hardly responsive to a change in such a country's patent policy. It follows that a small country will set its index of patent protection equal to zero in a Nash equilibrium.

If all countries choose positive patent strengths that are less than \bar{T} , equation (7) holds for every i . Then we can sum (7) across the J countries, which gives

$$J(C_c - C_m) - \pi = \gamma \left[C_m - C_c + \frac{C_c (\sum_j M_j) \bar{T}}{Q} \right] . \quad (8)$$

Then, for a given size of the world market, Q depends only on the *number* of countries J and not on the distribution of consumers and human capital across countries. Moreover, the greater is the number of countries, the weaker are the global incentives for innovation in a noncooperative equilibrium. As the number of countries grows large (holding constant the size of the world market), the aggregate incentives for innovation approach zero.¹⁶ Evidently, the free-rider problem becomes increasingly severe as the number of independent decision makers in the world economy expands.

¹⁶Suppose Q were to approach a finite number as $J \rightarrow \infty$. Then γ would approach a finite number as

Finally, note that the requirements for global efficiency do not depend on the number of countries. Again, the sum of all national welfare levels is a function of the aggregate world incentive for innovation. This sum is maximized when

$$C_c - C_m - \pi = \gamma \left[C_m - C_c + \frac{C_c \left(\sum_j M_j \right) \bar{T}}{Q^*} \right]. \quad (9)$$

Thus, if international compensation is possible, an efficient global patent treaty will have $\sum_j M_j \Omega_j = Q^*$, where Q^* is solved from (9). Notice that Q^* must exceed Q , the aggregate patent protection in the Nash equilibrium. Even if international compensation is not feasible, an efficient agreement will have $\sum_j M_j \Omega_j = Q^*$ for a range of distributions of world welfare.

2.4 Harmonization with the most protective country

We have concluded that global patent protection would be too weak without international coordination. But would it be too strong with the current international coordination, namely TRIPS? One way to characterize TRIPS in the context of our model is that TRIPS requires all other countries to harmonize their IPR standards with the pre-TRIPS standards of the most protective country. A similar view has been expressed by a few observers, such as Reichman (1995), and the assumption has been used to analyze multi-issue negotiations in the GATT/WTO by Lai and Qiu (2003).¹⁷ Under this assumption, is such a harmonization scheme going to be over-protective from a global welfare point of view? Suppose we apply best response function (7) to a country k such that $\Omega_k^E = \max\{\Omega_j^E\}_{j \in \mathcal{N}}$. Suppose we impose the restriction $\Omega_j = \Omega^* \forall j \in \mathcal{N}$ on first order conditions well, and the right-hand side of (8) would be finite. But the left-hand side of (8) approaches infinity as $J \rightarrow \infty$.

¹⁷If one examines the Ginarte-Park patent rights index for the periods 1960-1990, 1995, 2000 and 2005 (refer to Park 2005), one sees that the most protective country before TRIPS (i.e. 1960-1990) was the US, whose index was 4.14. By 2005, all developed or newly industrialized economies would have already adopted the patent standard required by TRIPS. What is the patent right index for countries that adopt the minimum requirement mandated by TRIPS? It turned out that it is about 4.1 (e.g. Israel 4.13, Australia 4.17, New Zealand 4.01, Norway 4.17). So harmonization with the pre-TRIPS standard of the US is more or less what the TRIPS mandated.

(9). It is easy to see that if $\Omega_k^E < \Omega^*$, then there is no over-protection of patent rights even if all countries harmonize their IPR standards with the pre-TRIPS standard of the most protective country in the world. What is the condition for $\Omega_k^E < \Omega^*$ to be true?

As national patent strengths are strategic substitutes, we can pin down the upper bound of Ω_k^E by finding the best response of country k, call it $\bar{\Omega}_k$, if all other countries do not protect at all. Invoking (7), we have

$$\begin{aligned} C_c - C_m - \mu_k \pi &= \frac{M_k}{M_k \bar{\Omega}_k} \gamma [\bar{\Omega}_k C_m + C_c (\bar{T} - \bar{\Omega}_k)] \\ \iff C_c - C_m - \mu_k \pi &= \gamma \left[C_m - C_c + \frac{C_c \bar{T}}{\bar{\Omega}_k} \right] \end{aligned} \quad (10)$$

If globally efficient harmonization occurs at Ω^* , then invoking (9) we have

$$\begin{aligned} C_c - C_m - \pi &= \gamma \left[C_m - C_c + \frac{C_c \left(\sum_j M_j \right) \bar{T}}{\left(\sum_j M_j \right) \Omega^*} \right] \\ \iff C_c - C_m - \pi &= \gamma \left[C_m - C_c + \frac{C_c \bar{T}}{\Omega^*} \right] \end{aligned} \quad (11)$$

Comparing (10) and (11), it is clear that $\Omega^* > \bar{\Omega}_k$.¹⁸ Therefore, we conclude with the following proposition.

Proposition 3 *Starting from Nash equilibrium, requiring all countries to adopt the equilibrium patent standard of the most protective country is unambiguously globally welfare-improving.*

The above proposition implies that TRIPS increases the welfare of the countries that are most protective before TRIPS but it hurts the countries that are least protective before TRIPS. However, the gains of the former group of countries outweigh the losses of the latter group of countries, as global welfare increases. The situation in a two-country

¹⁸In Grossman and Lai (2004), it is shown that if the R&D function is CES with elasticity of substitution between H and L equal to β , then $\gamma = \gamma(Q, \beta)$. When $\beta = 0$ (Cobb-Douglas), γ is independent of Q . When $\beta < 0$, γ is negatively related to Q . This implies that as long as $\beta \leq 0$, the current result holds. Note that $\beta \leq 0$ (which includes the Leontief case) means that capital and labor are not too substitutable in R&D, which is quite plausible.

case is shown in Figure 1. It shows that global harmonization with the North's pre-TRIPS standard is a movement from point E to point E'. As E' is still inside the global efficiency frontier, global welfare increases. Many commentators (e.g. Reichman 1995) believe that TRIPS is a quid pro quo between the North (the more protective countries before TRIPS) and the South (the less protective countries before TRIPS) in which the former opens their market to the exports of traditional goods from the latter while the latter agrees to harmonize its IPR standards with the pre-TRIPS standards of the former. This observation supports our result here: As the North gains more than the South loses in this global IPR harmonization scheme, the North has incentives to "bribe" the South to harmonize IPR. A detailed analysis of this sort is found in Lai and Qiu (2003).

3 Extended model with trade barriers and firm-bias

The conclusion that global IPR protection is too weak in the absence of international agreement can be met with skepticism. Many people point to the strong pharmaceutical lobbies in Washington to justify why they think global patent protection before TRIPS must have been already too strong rather than too weak. Moreover, the existence of trade barriers weakens the international spillovers that one nation confers on foreign countries when it strengthens domestic IPR protection. Therefore, I address here two key simplifications of the basic model: that governments put equal weights on consumer welfare and firm profits and that there are no trade barriers. In reality, governments are often biased in favor of domestic firms and trade barriers are non-trivial. Omitting these factors can bias the conclusion that global IPR protection is too weak in the non-cooperative equilibrium. Obviously, whether the conclusion of the basic model can be overturned depends on how large are the magnitudes of these two effects. The analytical task is to find out what values of firm-bias and trade barrier can sustain the original conclusion that there is under-protection of IPR in Nash equilibrium, and then judge whether these values are plausible.

I assume that trade barrier is captured by two components: the export penetration

rate, which is the probability that a good is exported to each foreign country; and trade cost, which consists of transport cost and import tariffs. Recent empirical trade literature documents that only a small fraction of firms export. To capture this phenomenon, I assume that a producer of differentiated goods has an exogenous probability θ of exporting to each foreign country.¹⁹ In addition, I assume that there is an iceberg trade cost equal to a fraction t of the production cost, and that there is a constant-elasticity demand curve faced by each consumer, with ϵ being the price elasticity of demand. Defining $y = (1 + t)^{-\epsilon+1}$, then y is an inverse measure of trade costs. To modify the equations of the basic model, we change C_m to $\theta y C_m$ and π to $\theta y \pi$ for goods that are traded.²⁰ Note that we assume that a firm always patent its good in all countries once it is developed. Once patented, the technology is disclosed. So, when patents are not in force consumer surplus is C_c whether a good was developed overseas or locally, as countries can always imitate foreign-developed goods when the patent is not in force, and these imitated goods are produced locally, and so there is no trade barrier.²¹

Let $1 + a$ be the weight a government puts on domestic profits when a weight of one is put on domestic consumer surplus in its objective function. The parameter a measures the firm-bias of governments. Note that this approach of assigning additional exogenous weight to firms as opposed to consumers is similar to what is done by Bagwell and Staiger

¹⁹It is not the purpose of my model to explain why the export penetration rate is a small fraction. For the purpose of this paper, it suffices to assume the export penetration rate to be exogenous.

²⁰Let the demand function be $x = Ap^{-\epsilon}$, where ϵ is the absolute value of elasticity of demand. Let p_m , x_m , π , and C_m be the monopoly price, monopoly quantity, monopoly profit, and consumer surplus under monopoly pricing, respectively, when trade cost is zero; and let p'_m , x'_m , π' , and C'_m be the corresponding variables when trade cost is equal to t times the production cost of each differentiated good. Let c be the unit cost of production and let $\epsilon = 1/(1 - \alpha)$, where $0 < \alpha < 1$ so that $\epsilon > 1$. Then, $p_m = c/\alpha$; $x_m = A(c/\alpha)^{-\epsilon}$; $C_m = \int_{p_m}^{\infty} Ap^{-\epsilon} dp = \frac{A}{\epsilon} \left(\frac{c}{\alpha}\right)^{-\epsilon+1}$ and $\pi = C_m$. Then, it can be easily shown that $p'_m/p_m = 1 + t$; $x'_m/x_m = (1 + t)^{-\epsilon}$; and $\pi'/\pi = C'_m/C_m = (1 + t)^{-\epsilon+1}$.

²¹I assume that an innovator patent his innovation all over the world before he learns to which countries, or whether, he would be able to export. Note that even if it turns out that a good is not exported to a foreign country, nobody in the foreign country can legally produce or sell the good locally while the patent for the good is in force. Under such circumstance, local consumers cannot enjoy the good while its patent is in force locally. When the patent is not in force, local imitators can produce the good with zero imitation cost, and the market becomes perfectly competitive.

(2002). They essentially put a weight of $1 + a$ on firms in the government's objective function, which they treat as a reduced form derived from the analysis of a political-economy equilibrium a la Grossman and Helpman (1994). Let v_i be the expected value of a patent of an invention by a firm in country i . Therefore, $v_i = \pi \left[\sum_{k \neq i} (\theta y M_k \Omega_k) + M_i \Omega_i \right]$.

It is useful to consider a multi-country setting, as the number of independent decision-making governments plays a crucial role in whether there is under-protection of IPR in Nash equilibrium. Let there be J countries in the set \mathcal{N} of countries in the world. Define $f_i \equiv C_c \bar{T} - (C_c - C_m) \Omega_i$ as the present discounted value of consumer surplus for a consumer in country i derived from consumption of a home-developed differentiated good over its product life; and define $f'_i \equiv C_c \bar{T} - (C_c - \theta y C_m) \Omega_i$ as the corresponding consumer surplus derived from consumption of a product developed by a foreign country. In a multi-country setting, the best-response function of country i is

$$\begin{aligned}
& \left(\sum_{j \neq i} \phi_j \right) (C_c - \theta y C_m) + \phi_i (C_c - C_m) - \phi_i (1 + a) \pi \\
= & \left(\sum_{j \neq i} \frac{\partial \phi_j}{\partial v_j} \frac{\partial v_j}{\partial \Omega_i} f'_i \right) + \frac{\partial \phi_i}{\partial v_i} \frac{\partial v_i}{\partial \Omega_i} f_i \\
= & \left(\sum_{j \neq i} \gamma \frac{\phi_j}{v_j} \right) \theta y \pi M_i f'_i + \gamma \frac{\phi_i}{v_i} \pi M_i f_i \tag{12}
\end{aligned}$$

The left-hand side (LHS) of the above equation is, in fact, the marginal cost per consumer in country i of strengthening IPR there. The first term is the loss in consumer surplus attributed to inventions from firms outside country i (note that while patent protection is in force in country i , each consumer only enjoys consumer surplus of $\theta y C_m$ from each foreign-developed product, but when patent protection ceases, domestic firms can imitate the good at no cost, and so each consumer obtains consumer surplus of C_c from the good); the second term is the loss of consumer surplus attributed to inventions from country i ; and the third term is the offsetting of the losses of consumer surplus by gains in profits of firms in country i . The right-hand side (RHS) is the marginal benefit per consumer in country i . The first term is the increase in consumer welfare in country i due to increases in flows of innovations from firms outside country i ; the second term is

the increase in consumer welfare in country i due to the increase in flow of innovation from country i . If I define the left-hand side as $MC_i(a)$ and the right-hand side as MB_i , then $\frac{1}{M_i} \frac{\partial W_i(a)}{\partial \Omega_i} = MB_i - MC_i(a)$, where $W_i(a)$ is the Government i 's objective function. (Hereinafter, I put an argument 'a' after the name of a function if firm-bias affects the value of the function.)²²

It can be easily shown that the first-order condition for global welfare maximization with respect to the choice of Ω_i is given by

$$\begin{aligned}
& M_i \left[MC_i(a) + \pi a \phi_i - \theta y \pi \left(\sum_{j \neq i} \phi_j \right) \right] \\
= & M_i \times MB_i + \sum_{k \neq i} \left(\sum_{j \neq k} \frac{\partial \phi_j}{\partial v_j} \frac{\partial v_j}{\partial \Omega_i} M_k f'_k \right) + \sum_{k \neq i} \frac{\partial \phi_k}{\partial v_k} \frac{\partial v_k}{\partial \Omega_i} M_k f_k \\
= & M_i \times MB_i + \sum_{k \neq i} \left[M_k \left(\gamma \frac{\phi_i}{v_i} M_i \pi f'_k \right) + M_k \left(\sum_{j \neq k, i} \gamma \frac{\phi_j}{v_j} \right) \theta y M_i \pi f'_k \right] + \sum_{k \neq i} M_k \left(\gamma \frac{\phi_k}{v_k} \theta y M_i \pi f_k \right)
\end{aligned} \tag{13}$$

The LHS is the marginal global cost of strengthening IPR protection in that country. The second term inside the squared brackets is the benefit to country i that will not be taken into account when IPR protection in country i is chosen to maximize global welfare instead of to maximize government i 's firm-biased objective (therefore it is an addition to marginal cost); the third term inside the squared brackets reduces the global marginal cost as it takes into account the increases in profits of firms outside of country i . The

²²To get some feeling of concreteness, we can look at the two-country case. In Nash equilibrium, the best response functions of the North and the South are, respectively,

$$\begin{aligned}
& \phi_S (C_c - \theta y C_m) + \phi_N (C_c - C_m) - \phi_N (1 + a) \pi \\
= & \frac{\gamma \theta y \phi_S M_N \left[C_c \bar{T} - (C_c - \theta y C_m) \Omega_N \right]}{\theta y M_N \Omega_N + M_S \Omega_S} + \frac{\gamma \phi_N M_N \left[C_c \bar{T} - (C_c - C_m) \Omega_N \right]}{\theta y M_S \Omega_S + M_N \Omega_N}
\end{aligned}$$

and

$$\begin{aligned}
& \phi_N (C_c - \theta y C_m) + \phi_S (C_c - C_m) - \phi_S (1 + a) \pi \\
= & \frac{\gamma \theta y \phi_N M_S \left[C_c \bar{T} - (C_c - \theta y C_m) \Omega_S \right]}{\theta y M_S \Omega_S + M_N \Omega_N} + \frac{\gamma \phi_S M_S \left[C_c \bar{T} - (C_c - C_m) \Omega_S \right]}{\theta y M_N \Omega_N + M_S \Omega_S}
\end{aligned}$$

RHS represents the marginal global benefit of strengthening IPR in country i . The second term and the third term are both increases in welfare of consumers outside of country i . The second term is due to faster foreign innovations, while the third term is due to faster domestic innovations (“foreign” and “domestic” here are relative to each country outside of country i). The second term is further broken down into the effect due to faster innovation in country i (first term inside squared brackets on RHS) and that due to faster innovations outside of country i (second term inside squared brackets on RHS). The cross-border externalities of IPR protection are captured by the third term inside the squared brackets on the LHS plus the second and third terms on the RHS. It is apparent that since an increase in trade barrier (a decrease in θy) leads to smaller international spillovers, the likelihood of under-protection of IPR in equilibrium is lower. Likewise, an increase in firm-bias (an increase in a) reduces the gap between marginal global benefit and marginal national benefit, making under-protection of IPR less likely.²³

Let us define LHS_{13}/M_i of the first order condition above as MC_i^w and RHS_{13}/M_i as MB_i^w . It follows that $\frac{1}{M_i} \frac{\partial W^w}{\partial \Omega_i} = MB_i^w - MC_i^w$, where W^w is world welfare (without bias towards firm profits).

In the basic model, we can find a functional relationship between the global strength

²³In the two-country case, the first order conditions for the choices of Ω_N and Ω_S respectively for maximization of global welfare are

$$\begin{aligned}
& M_N [\phi_S (C_c - \theta y C_m - \theta y \pi) + \phi_N (C_c - C_m - \pi)] \\
= & \frac{\gamma \phi_S \theta y M_N \left\{ M_N [C_c \bar{T} - (C_c - \theta y C_m) \Omega_N] + M_S [C_c \bar{T} - (C_c - C_m) \Omega_S] \right\}}{\theta y M_N \Omega_N + M_S \Omega_S} \\
& + \frac{\gamma \phi_N M_N \left\{ M_N [C_c \bar{T} - (C_c - C_m) \Omega_N] + M_S [C_c \bar{T} - (C_c - \theta y C_m) \Omega_S] \right\}}{\theta y M_S \Omega_S + M_N \Omega_N}
\end{aligned}$$

and

$$\begin{aligned}
& M_S [\phi_N (C_c - \theta y C_m - \theta y \pi) + \phi_S (C_c - C_m - \pi)] \\
= & \frac{\gamma \phi_N \theta y M_S \left\{ M_S [C_c \bar{T} - (C_c - \theta y C_m) \Omega_S] + M_N [C_c \bar{T} - (C_c - C_m) \Omega_N] \right\}}{\theta y M_S \Omega_S + M_N \Omega_N} \\
& + \frac{\gamma \phi_S M_S \left\{ M_S [C_c \bar{T} - (C_c - C_m) \Omega_S] + M_N [C_c \bar{T} - (C_c - \theta y C_m) \Omega_N] \right\}}{\theta y M_N \Omega_N + M_S \Omega_S}
\end{aligned}$$

of patent protection and global welfare. The same strength of global patent protection creates the same amount of total deadweight losses (what I call static losses) and aggregate flow of new differentiated goods (what I call dynamic gains) in each period. As long as the global strength of patent protection is the same, global welfare is the same, regardless of the combination of individual countries' strengths of patent protection. Therefore, the global optimum is a continuum of combinations of national strengths of patent protection that maximize global welfare. However, this will not be true in this extended model. In this more general model with trade barriers, there does not exist a scalar measure of the global strength of patent protection such that there is a functional relationship between the global strength of protection and global welfare. Despite this problem, I am able to calculate a sufficient condition for global under-protection of patents, as shown below.

3.1 Is there global under-protection of IPR?

I define under-protection as a situation when, starting from Nash equilibrium, global welfare increases as a result of some positive changes in all $\{\Omega_i\}_{i \in \mathcal{N}}$ (where the magnitudes of increase are not necessarily equal). The point of the analysis is to come up with a sufficient condition under which, starting from Nash equilibrium $\{\Omega_i^E\}_{i \in \mathcal{N}}$, some simultaneous (but not necessarily equal) increases in IPR protection of all countries is globally welfare-improving. Note that increases in the strengths of protection in all countries raise the values of all patents. This increases the global deadweight losses, but gives a boost to the rate of innovation. To simplify the analysis, I focus on changes in $\{\Omega_i\}_{i \in \mathcal{N}}$ such that $M_i d\Omega_i = d\bar{\Omega}$ for all i . I want to find a sufficient condition under which such changes lead to an increase in global welfare. In other words, I seek a condition under which the marginal global benefit outweighs the marginal global cost.

First I prove the following lemma:

Lemma 1. A sufficient condition for under-protection of IPR in Nash equilibrium is

$$\sum_i \frac{1}{M_i} \frac{\partial W^w}{\partial \Omega_i} > 0 \text{ for all } \{\Omega_i\}_{i \in \mathcal{N}} \text{ such that } \sum_i \frac{1}{M_i} \frac{\partial W_i(a)}{\partial \Omega_i} = 0.$$

Proof. A sufficient condition for under-protection is

$$\sum_i \frac{1}{M_i} \frac{\partial W^w}{\partial \Omega_i} > 0 \text{ in Nash equilibrium } \{\Omega_i^E\}_{i \in \mathcal{N}}$$

This is true because $\sum_i \frac{1}{M_i} \frac{\partial W^w}{\partial \Omega_i} > 0$ implies that if we increase each Ω_i in $\{\Omega_i^E\}_{i \in \mathcal{N}}$ such that $M_i d\Omega_i = d\bar{\Omega} \quad \forall i$, then $dW^w = \left(\sum_i \frac{\partial W^w}{\partial \Omega_i} d\Omega_i\right) = \left(\sum_i \frac{1}{M_i} \frac{\partial W^w}{\partial \Omega_i}\right) d\bar{\Omega} > 0$. That is, global welfare increases as each Ω_i increases slightly such that $\frac{d\Omega_i}{d\Omega_j} = \frac{M_j}{M_i}$ for all $i \neq j$. This clearly indicates under-protection at Nash equilibrium. Moreover, since $\frac{\partial W_i(a)}{\partial \Omega_i} = 0$ for all i in Nash equilibrium, $\sum_i \frac{1}{M_i} \frac{\partial W_i(a)}{\partial \Omega_i} = 0$ includes the Nash equilibrium as a special case. ■

To understand Lemma 1 better, let us consider a two-country case. First refer to Figure 2 for an idea of the relationship between Nash equilibrium and global optimum. In that diagram, point E is the Nash equilibrium while point G is the global optimum. BRF-S and BRF-N are the best response functions of South and North respectively. Point G is at the intersection of the curves $\frac{\partial W^w}{\partial \Omega_S} = 0$ and $\frac{\partial W^w}{\partial \Omega_N} = 0$, which are not shown.²⁴ It is not hard to see that starting from any point on the iso-global-welfare line to the left of GG (defined by $\frac{1}{M_S} \frac{\partial W^w}{\partial \Omega_S} + \frac{1}{M_N} \frac{\partial W^w}{\partial \Omega_N} = 0$), any small increase in Ω_S and Ω_N such that $\frac{d\Omega_N}{d\Omega_S} = \frac{M_S}{M_N}$ would increase W^w . In the context of Figure 2, a necessary and sufficient condition for there to be under-protection in Nash equilibrium is that point E is to the left of the curve GG.²⁵

<Figure 2 and 3 about here>

Figure 3 shows the relationship between the curves GG and EE (defined by $\frac{1}{M_S} \frac{\partial W_S(a)}{\partial \Omega_S} + \frac{1}{M_N} \frac{\partial W_N(a)}{\partial \Omega_N} = 0$). The curves FOC-S and FOC-N are the first order conditions for maximization of global welfare with respect to the choice of Ω_S and Ω_N respectively. In the context of Figure 3, a sufficient condition for point E to be on the left of GG is that EE

²⁴Note that the slopes of the iso-global-welfare lines $W^w = \bar{W}$ are always equal to $\frac{M_S}{M_N}$ at their intersection with the line $\frac{1}{M_S} \frac{\partial W^w}{\partial \Omega_S} + \frac{1}{M_N} \frac{\partial W^w}{\partial \Omega_N} = 0$. This is because, along $W^w = \bar{W}$, $\frac{d\Omega_N}{d\Omega_S} = -\left(\frac{\partial W^w}{\partial \Omega_S} / \frac{\partial W^w}{\partial \Omega_N}\right)$. But at any point on the curve $\frac{1}{M_S} \frac{\partial W^w}{\partial \Omega_S} + \frac{1}{M_N} \frac{\partial W^w}{\partial \Omega_N} = 0$, we have $-\left(\frac{\partial W^w}{\partial \Omega_S} / \frac{\partial W^w}{\partial \Omega_N}\right) = \frac{M_S}{M_N}$.

²⁵Note that if point E is to the right of GG, then any simultaneous small decrease of Ω_S and Ω_N such that $\frac{d\Omega_N}{d\Omega_S} = \frac{M_S}{M_N}$ would increase W^w .

is to the left of curve GG. And this is exactly the condition stated in Lemma 1. If this condition is satisfied, at any point that lies on EE (including the Nash equilibrium point E), any small change in Ω_S and Ω_N such that $M_S d\Omega_S = M_N d\Omega_N$ would increase global welfare, since $\frac{1}{M_S} \frac{\partial W^w}{\partial \Omega_S} + \frac{1}{M_N} \frac{\partial W^w}{\partial \Omega_N} > 0$. Proposition 4 below provides a sufficient condition for the EE to be on the left of GG. Therefore, our next step is to prove the following proposition:

Proposition 4 *A sufficient condition for under-protection of IPR in Nash equilibrium when there are trade barriers and firm-bias is*

$$(J - 1) \theta y > a. \tag{14}$$

Proof. See the appendix. ■

To check that $(J - 1) \theta y > a$ is a reasonable condition, note that in the special case of the basic model, when there are two countries ($J = 2$), $\theta y = 1$ and $a = 0$, the condition is satisfied. Moreover, it accords with the intuition that the free-rider problem gets more serious when there are more countries playing the patent-setting game, for a larger J leads to more under-protection. It also is consistent with the notions that trade barriers weaken the cross-border externality of IPR protection, because a smaller θy leads to less under-protection, and that stronger government bias towards patent-holding firms tends to strengthen patents, for a larger a leads to less under-protection.

What is a reasonable value for a ? In the political-economy literature (Grossman and Helpman 1994; Maggi and Goldberg 1999), researchers have tried to estimate the weight the U.S. government puts on campaign contributions when it puts a weight of unity on welfare. They rarely come up with a number more than 0.5. Since this is a preference parameter, it should be the same in the context of patent protection. Suppose there is a patent lobby, and suppose there is no consumer lobby, nor is there lobbying from other sectors of the economy. Based on these suppositions, it is easy to show that the value the government puts on campaign contributions is exactly the same as a in the present model.²⁶

²⁶A proof is available from the author upon request.

What is a reasonable value for J ? This is the number of independent government decision-makers in the patent-setting game. Thus, it is the number of countries in the world that consume and trade patent-sensitive goods, and that adopt neither zero nor full patent protection. Ginarte and Park (1997) construct a patent rights index for a large number of countries, and none of the fifty most innovative of them is reported to have zero protection or full protection. From the data set in the World Intellectual Property Organization (WIPO) website, I find that residents of 39 countries obtained patents from the US Patent Office in the years 1996-1999, and residents of 41 countries obtained patents from the European Patent Office during this period.²⁷ To be conservative, I only consider the thirty most innovative countries as measured by the average number of patents they obtained from the US Patent Office. Therefore, assume that $J = 30$.

What is a reasonable value for θ ? Eaton, Kortum and Kramarz (2004) report that in 1986 only 17.4% of French manufacturing firms exported, and of those who exported, only 19.7% exported to ten or more countries. Moreover, in 1987, only 14.6 % of US manufacturing firms exported. Bernard, Eaton, Jensen and Kortum (2003) report that 79% of US manufacturing plants did not export at all in 1992. We expect many patent-sensitive goods, such as pharmaceuticals, are quite tradeable. Suppose the fraction of firms that do not export at all is 0.2. With our assumption, the probability of a firm exporting to n markets is determined a binomial distribution $\binom{J}{n}\theta^n(1-\theta)^{J-n}$. So, for $J = 30$ and $n = 0$, we have $\binom{30}{0}\theta^0(1-\theta)^{30} = 0.2$, which yields $\theta = 0.052$. So, we adopt $\theta = 0.05$. That is, one out of twenty domestically developed patent-sensitive goods is exported to each foreign country.

When $a = 0.5$, $\theta = 0.05$, and $J = 30$, a sufficient condition for the Nash equilibrium to be under-protecting patents is $\theta y > 0.345$. From Lai, Wong and Yan (2007), I obtain the average estimate of elasticity of demand ϵ of patent-sensitive goods out of thirty studies / countries as 5.63. So, I assume $\epsilon = 5$. Then the sufficient condition reduces to $t < 0.3$, i.e. the iceberg trade cost is less than 30% of production cost. I believe that this condition is likely to be satisfied for most patent-sensitive products.²⁸ So, based on this

²⁷For the WIPO website, refer to <http://www.wipo.int/ipstats/en/statistics/patents/>

²⁸Hummels (1999) found that the ad valorem freight rate of machinery and transport equipment for a

rough calculation, I conclude that global patent protection in the absence of international coordination is probably too weak.

As a final note in this subsection, I recognize that some people may argue that the globally optimal combination of strengths of national patent protection should take into account the politically-augmented objective function of each national government, as these functions reflect the preferences of each government, which represents each country in international negotiations. If maximizing the sum of the politically-augmented objective functions is the goal of international coordination, then one simply remove the term $+\pi a\phi_i$ inside the squared brackets on the LHS of equation (13). In this case, it is clear that there is always under-protection of patents in each country, as the marginal global cost is lower than the marginal national cost while the marginal global benefit is higher than the marginal national benefit. There are unambiguous positive cross-border externalities as the increases in profits of foreign firms and consumer surplus of foreign consumers due to induced innovations are not taken into account as Ω_i increases, just like in the basic model. The spillovers are smaller in this case, as there are trade barriers.

3.2 Harmonization with the most protective country

What is the condition to guarantee that the harmonization scheme described in subsection 2.4 does not over-protect IPR in the global economy? Suppose best response function (12) is applied to country k where $\Omega_k^E = \max\{\Omega_j^E\}_{j \in \mathcal{N}}$. Suppose we sum up all the J first order conditions (13) and impose the restriction $\Omega_j = \Omega^* \forall j \in \mathcal{N}$ on this equation. As Ω^* is the globally efficient harmonized patent strength, $\Omega_k^E < \Omega^*$ is the condition that we are looking for.

sample of six non-land-locked countries was around 5% on average (Table 1 in Hummels (1999), Trade Weighted Average Freight Rate). It was 2% for the US. The average freight rate of one important patent-sensitive good, pharmaceutical, was around 2.5% (it was 1.2% for the US). The tariffs on patent sensitive goods are usually quite low. For example, the tariffs on pharmaceuticals are mostly zero in the US, EU and Japan. They are about 6% in China. The tariffs on machinery are mostly below 2% in US, EU and Japan. The tariffs on polymerization products are less than 2% in US, EU and Japan, and about 6.5% in China.

As in subsection 2.4, we find the upper bound $\overline{\Omega}_k$ of Ω_k^E , which is the best response of country k given that all other countries do not protect. Applying $\overline{\Omega}_k = \Omega_k$ and $\Omega_i = 0 \forall i \neq k$ to equation (12), and manipulating the resulting equation, we get

$$\begin{aligned} & \left(\sum_{j \neq k} \phi_j \right) (C_c - \theta y C_m) + \phi_k (C_c - C_m) - \phi_k (1 + a) \pi \\ = & \frac{\left\{ \sum_{j \neq k} \gamma \phi_j [C_c \overline{T} - (C_c - \theta y C_m) \overline{\Omega}_k] \right\} + \gamma \phi_k [C_c \overline{T} - (C_c - C_m) \overline{\Omega}_k]}{\overline{\Omega}_k} \end{aligned}$$

Simplifying, multiplying both sides by $\sum_{j \in \mathcal{N}} M_j$ and shifting a term to the left hand side, we have

$$\begin{aligned} & (\sum M_j) (\sum \phi_j) (C_c - \theta y C_m) - (1 + \gamma) \phi_k (\sum M_j) (1 - \theta y) C_m - \phi_k (\sum M_j) (1 + a) \pi \\ = & \frac{\gamma (\sum M_j) (\sum \phi_j) C_c \overline{T}}{\overline{\Omega}_k} - \gamma (\sum M_j) (\sum \phi_j) (C_c - \theta y C_m) \end{aligned} \quad (15)$$

where we have simplified notation by defining $\sum M_j \equiv \sum_{j \in \mathcal{N}} M_j$ and $\sum \phi_j \equiv \sum_{j \in \mathcal{N}} \phi_j$.

Summing up all J first order conditions (13) and applying $\Omega_j = \Omega^* \forall j \in \mathcal{N}$, we have

$$\begin{aligned} & \sum_{i \in \mathcal{N}} \left\{ M_i \left[\left(\sum_{j \neq i} \phi_j \right) (C_c - \theta y C_m - \theta y \pi) + \phi_i (C_c - C_m - \pi) \right] \right\} \\ = & \sum_{i \in \mathcal{N}} \frac{\gamma \phi_i \left\{ \sum_{j \neq i} M_j [C_c \overline{T} - (C_c - \theta y C_m) \Omega^*] + M_i [C_c \overline{T} - (C_c - C_m) \Omega^*] \right\}}{\Omega^*} \end{aligned}$$

Simplifying and shifting a term to the left hand side, we have

$$\begin{aligned} & (\sum M_j) (\sum \phi_j) (C_c - \theta y C_m - \theta y \pi) - (1 + \gamma) (1 - \theta y) (\sum M_j \phi_j) C_m - (1 - \theta y) (\sum M_j \phi_j) \pi \\ = & \frac{\gamma (\sum M_j) (\sum \phi_j) C_c \overline{T}}{\Omega^*} - \gamma (\sum M_j) (\sum \phi_j) (C_c - \theta y C_m) \end{aligned} \quad (16)$$

where $\sum M_j \phi_j \equiv \sum_{j \in \mathcal{N}} M_j \phi_j$.

A sufficient condition for $\overline{\Omega}_k < \Omega^*$ is therefore $LHS_{15} - LHS_{16} > 0$, which is equivalent to

$$\begin{aligned} & [(\sum M_j) (\sum \phi_j) - (\sum M_j \phi_j)] \theta y \pi - (1 + \gamma) (1 - \theta y) [\phi_k (\sum M_j) - (\sum M_j \phi_j)] C_m \\ & \quad - [\phi_k (\sum M_j) - (\sum M_j \phi_j)] \pi - \phi_k (\sum M_j) a \pi > 0 \end{aligned} \quad (17)$$

Recalling $\mu_k \equiv \phi_k / \sum \phi_j$ and defining $\Delta \equiv (\sum M_j \phi_j) / [(\sum M_j) (\sum \phi_j)]$, we get

Proposition 5 *A sufficient condition for there to be no over-protection of global IPR by requiring all countries to harmonize their patent standard with that of the most innovative country in Nash equilibrium is*

$$\theta y > \frac{\frac{a\mu_k}{\mu_k - \Delta} + 2 + \gamma}{\frac{1 - \mu_k}{\mu_k - \Delta} + 2 + \gamma}, \quad (18)$$

assuming each consumer is faced with a constant elasticity demand curve.

Proof. Assuming constant elasticity demand $x = Ap^{-\epsilon}$ faced by each consumer, it can be easily shown that $C_m = \pi$ (see footnote 20). Substituting into inequality (17) and manipulating, we obtain (18). ■

Let us make the (realistic) assumption that the most protective country before TRIPS is also the most innovative, i.e. $\phi_k = \max\{\phi_j\}_{j \in \mathcal{N}}$. Assume further that M_k is greater than the average market size, i.e. $M_k > \sum M_j/J$, which is realistic. A few observations are in order. First, if $\theta y = 1$ and $a = 0$, then the condition (18) is clearly satisfied. This confirms the result in subsection 2.4. Second, the condition is more likely satisfied if a is smaller or θy is larger. This makes sense as they tend to make global under-protection more likely in Nash equilibrium. Third, as ϕ_k gets closer to $\sum \phi_j/J$, it makes μ_k and $\mu_k - \Delta$ both smaller, which in turn makes the right hand side of (18) smaller, making the condition more likely to be satisfied.²⁹ In other words, it is less likely for there to be over-protection when the distribution of innovative capability among countries is not too skewed. This makes sense as harmonization with the standard of the most innovative (and protective) country becomes more onerous for the other countries if the most protective country is a lot more protective than the rest of the countries. It is clear that the condition stated in Proposition 5 is more stringent than the one stated in Proposition 4, as the former requires

²⁹First, as ϕ_k gets further away from $\sum \phi_j/J$, it makes μ_k larger. But it also makes $\mu_k - \Delta$ larger. This can be seen from the fact that $\mu_k - \Delta$ increases from 0 to $1 - M_k/\sum M_j$ as ϕ_k increases from $\sum \phi_j/J$ to 1 (i.e. as the distribution of ϕ changes from totally even to totally skewed). Second, we need $y > 1$, which means that $a\mu_k < 1 - \mu_k$. Once this is established, we see that an increase in μ_k keeping $\mu_k - \Delta$ constant, or an increase in $\mu_k - \Delta$ keeping μ_k constant both lead to an increase in the right hand side of (18). Applying the chain rule, we can conclude that the right hand side of (18) increases with ϕ_k .

not only that patent rights are under-protected in Nash equilibrium, but sufficiently so.³⁰

Therefore, we need to know the distributions of M_i and ϕ_i among the countries. We can proxy M_i by the dollar value of the consumption of patent-sensitive goods by each country and proxy ϕ_i by the number of patents granted to residents of each country by the U.S. patent office (adjusted for home bias of American patentees). Data on M_i for 1996-1999 are obtained from Lai, Wong and Yan (2007), and data on ϕ_i for 1996-1999 are from the website of WIPO. I use data for the thirty most innovative countries except Russia (for lack of market size data). Going beyond the top thirty would not be very meaningful as the thirtieth most innovative country, Greece, only has 17 patents granted to its residents per year by the US Patent Office during 1996-1999.

From the data, I obtain $\mu_k = 0.48$ and $\Delta = 0.19$, and therefore $\mu_k - \Delta = 0.29$.³¹ With these data inserted into (18), I find that for $a = 0.5$, (18) is reduced to

$$\theta y > \frac{2.83 + \gamma}{3.79 + \gamma}.$$

As before, I assume $\epsilon = 5$. I further assume that the labor share of R&D to be $b = 0.5$, which yields $\gamma = 1$. Assuming $\theta = 0.05$ as before, we get $y > 16$, which is impossible to achieve, as $y < 1$ is required.³² As the sufficient condition is so far from being satisfied, I conclude that **the distribution of innovative capability among countries is so skewed that requiring all countries to harmonize their patent standards with that of the most protective (and most innovative) country in Nash equilibrium (i.e. the US) likely leads to over-protection of patent rights from the global welfare point of view.**

³⁰When ϕ_j is the same for all j , the condition becomes $(J-1)\theta y > a$, which is the same as the condition for under-protection in Nash equilibrium as stated in Proposition 4. On the other extreme, when the distribution of ϕ_j is so skewed towards ϕ_k that $\phi_k \rightarrow 1$, it can be easily shown that $LHS_{15} - LHS_{16} \leq 0$, with equality only when $y = 1$ and $a = 0$.

³¹ μ_k ranges from 0.11 to 1 as the distribution of ϕ changes from totally even to totally skewed, while $\mu_k - \Delta$ ranges from 0 to 0.64 as ϕ changes from totally even to totally skewed. Therefore, the current distribution of ϕ is somewhere in the middle.

³²To be very conservative and assume that $a = 0$ and $b = 0.1$ (which implies $\gamma = 0.11$) would yield $y > 10.8$, still an insurmountable gap.

4 Conclusion

I extend the basic model of Grossman and Lai (2004) by introducing firm-biased government preferences and trade barriers. I make use of the estimates of a parameter from the political economy literature to proxy for the degree of governments' firm-bias. Then I calculate the range of trade barriers that is sufficient to give rise to under-protection of patents in the global system in Nash equilibrium. I make the judgment that the true trade barrier between countries very likely falls within this range of under-protection. Therefore, I conclude that there probably would be under-protection of patent rights without international policy coordination in IPR protection. It means that the free-rider problem with a large number of independent players overrides the effects of firm-bias and trade barriers, giving rise to too low a rate of innovation in the world.

Does requiring all countries to harmonize their patent standards with the equilibrium standard of the most innovative country lead to global over-protection of patent rights? To answer this question requires us to know the distribution of innovative capability among countries as well as the distribution of the domestic market size among countries. Drawing on estimates of these variables for thirty countries, and applying them to my extended model, I conclude that such harmonization quite likely leads to global over-protection of patent rights. Therefore, it is likely that global patent protection is too strong if TRIPS is fully enforced.

I have only considered expanding-variety type of innovation in our model. Other types of innovation, such as quality-improvement type of innovation, have not been considered. If innovation takes the form of improvement of the quality of state of the art technology, then as a country strengthens patent protection, such as by increasing the patent breadth, it is not clear if foreign innovators can benefit from it, as it is harder for an innovation to obtain a non-infringing patent, though once patented its monopoly position lasts longer. It is also not clear if foreign consumers benefit from it as the rate of innovation may not be made faster by such a policy. Therefore, we are not sure of the nature and the signs of the resulting cross-border externalities and their net effect. This is left for future work.

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Appendix

A Proof of Proposition 4

Recall that equation (12) is equivalent to $\frac{1}{M_i} \frac{\partial W_i(a)}{\partial \Omega_i} = 0$ while (13) is equivalent to $\frac{1}{M_i} \frac{\partial W^w}{\partial \Omega_i} = 0$. We have established in Lemma 1 that a sufficient condition for under-protection is $\left(\sum_i \frac{1}{M_i} \frac{\partial W^w}{\partial \Omega_i}\right) > 0$ for all combinations of $\{\Omega_i\}_{i \in \mathcal{N}}$ that satisfy $\sum_i \frac{1}{M_i} \frac{\partial W_i(a)}{\partial \Omega_i} = 0$. From equation (13), we know this condition is equivalent to

$$\begin{aligned} & \sum_i \left[\pi a \phi_i - \theta y \pi \left(\sum_{j \neq i} \phi_j \right) \right] \\ < \sum_i \left[\sum_{k \neq i} \left(\gamma \frac{\phi_i}{v_i} \pi M_i f'_k + \sum_{j \neq k, i} \gamma \frac{\phi_j}{v_j} \theta y \pi M_i f'_k \right) + \sum_{k \neq i} \gamma \frac{\phi_k}{v_k} \theta y \pi M_i f_k \right] \end{aligned} \quad (19)$$

for all combinations of $\{\Omega_i\}_{i \in \mathcal{N}}$ that satisfy $\sum_i \frac{1}{M_i} \frac{\partial W_i(a)}{\partial \Omega_i} = 0$.

But the RHS of (19) is greater than zero, as there are positive cross-border externalities as a country strengthens its patent protection. Therefore, a sufficient condition for (19) to hold is

$$\begin{aligned} & \sum_i \left[\pi a \phi_i - \theta y \pi \left(\sum_{j \neq i} \phi_j \right) \right] < 0 \\ \iff & a \left(\sum_i \phi_i \right) - (J-1) \theta y \left(\sum_j \phi_j \right) < 0 \\ & \iff (J-1) \theta y > a \end{aligned}$$

which is (14). ■

B Data for M and ϕ

The variable M_i is proxied by the average dollar value of consumption (or use) of patent-sensitive goods per year by country i over the years 1996-1999 (estimated by Lai, Wong and Yan 2007). The variable ϕ_i is proxied by the average number of patents granted to the resident of country i by the US patent office per year over the years 1996-1999

(obtained from the WIPO website). However, to adjust for home-bias of the US data, we calculate the US innovative capability as the mean of an upper bound and a lower bound. The upper bound is the yearly average of the actual number of patents granted to US residents by the US patent office, P_{US}^{US} , where P_i^j denotes the number of patents granted to residents of country i by country j. This is an upper bound because it probably overstates the innovative capability of the US because even relatively trivial inventions might be patented in the US by US residents as the cost of patenting and subsequent working of the patents by domestic residents is relatively low. This is the home bias effect. The lower bound estimate is obtained by the formula

$$\widetilde{P}_{US}^{US} = \frac{P_{US}^{EPO}}{P_{Japan}^{EPO}} \times P_{Japan}^{US}.$$

The idea is that American capability to obtain patents relative to that of Japan in Europe is approximately equal to American capability to obtain patents relative to that of Japan in the US. Comparison with Japan is chosen because its innovative capability is comparable to that of the US while other countries are much further behind. The reason for choosing patents awarded in Europe is because European countries have a longer tradition of patent protection and have been having patent systems similar to that of the US. Japan, on the other hand, has a more liberal patent system with narrower protection than in the US and in Europe. Therefore, calibration with the Japanese patent counts is not done. The estimate \widetilde{P}_{US}^{US} is considered a lower bound of US innovative capability as some useful American innovations are not patented overseas perhaps because they are relatively less significant (but may be still useful). This is just the opposite of the home bias effect.

The estimated innovative capability of the US is therefore calculated as

$$\widehat{\phi}_{US} = \frac{\widetilde{P}_{US}^{US} + P_{US}^{US}}{2}$$

After taking the above into account, we obtain Table 1, which shows the patent counts and market sizes of the thirty most innovative countries. It can be easily calculated that $\phi_k / (\sum \phi_j) = 0.48$, $(\sum M_j \phi_j) / (\sum M_j) (\sum \phi_j) = 0.19$.

<Table 1 about here>



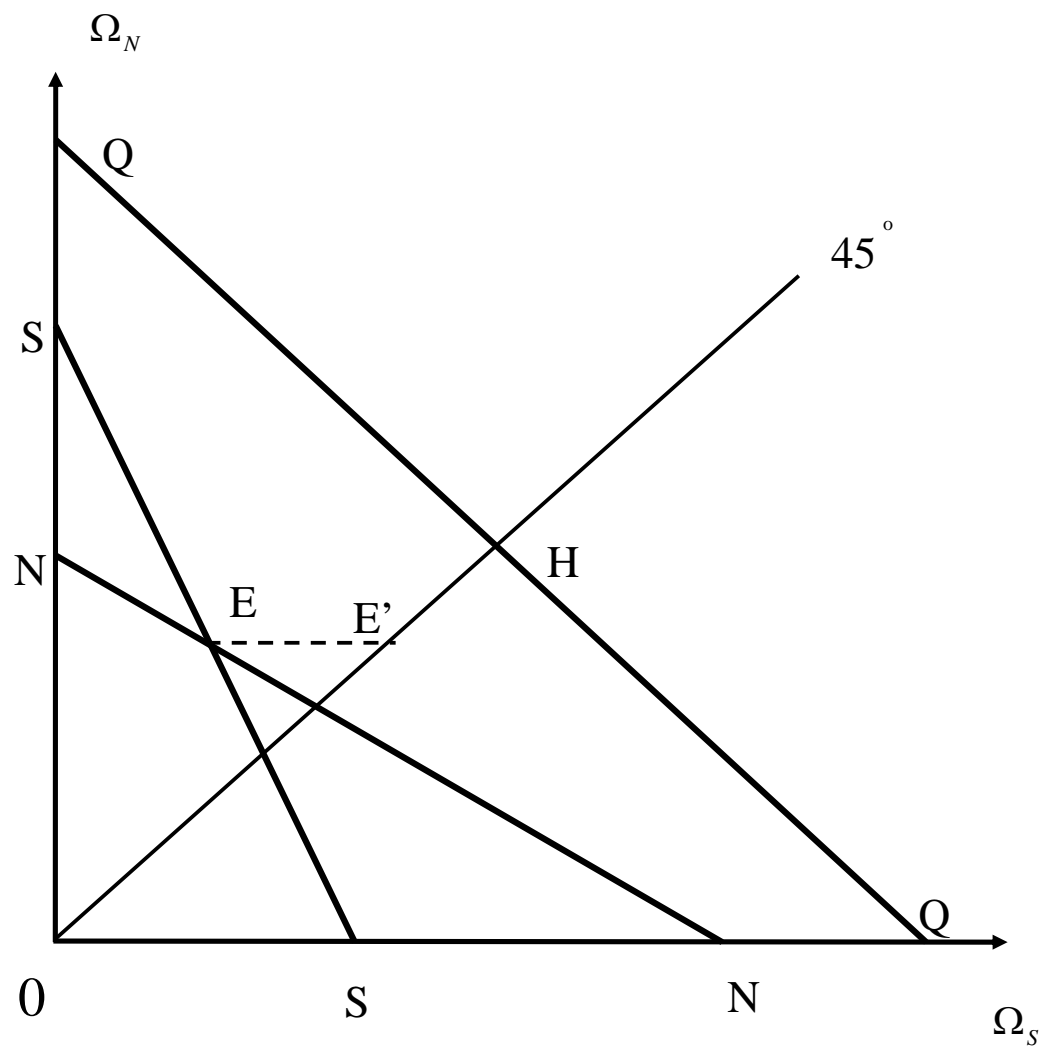
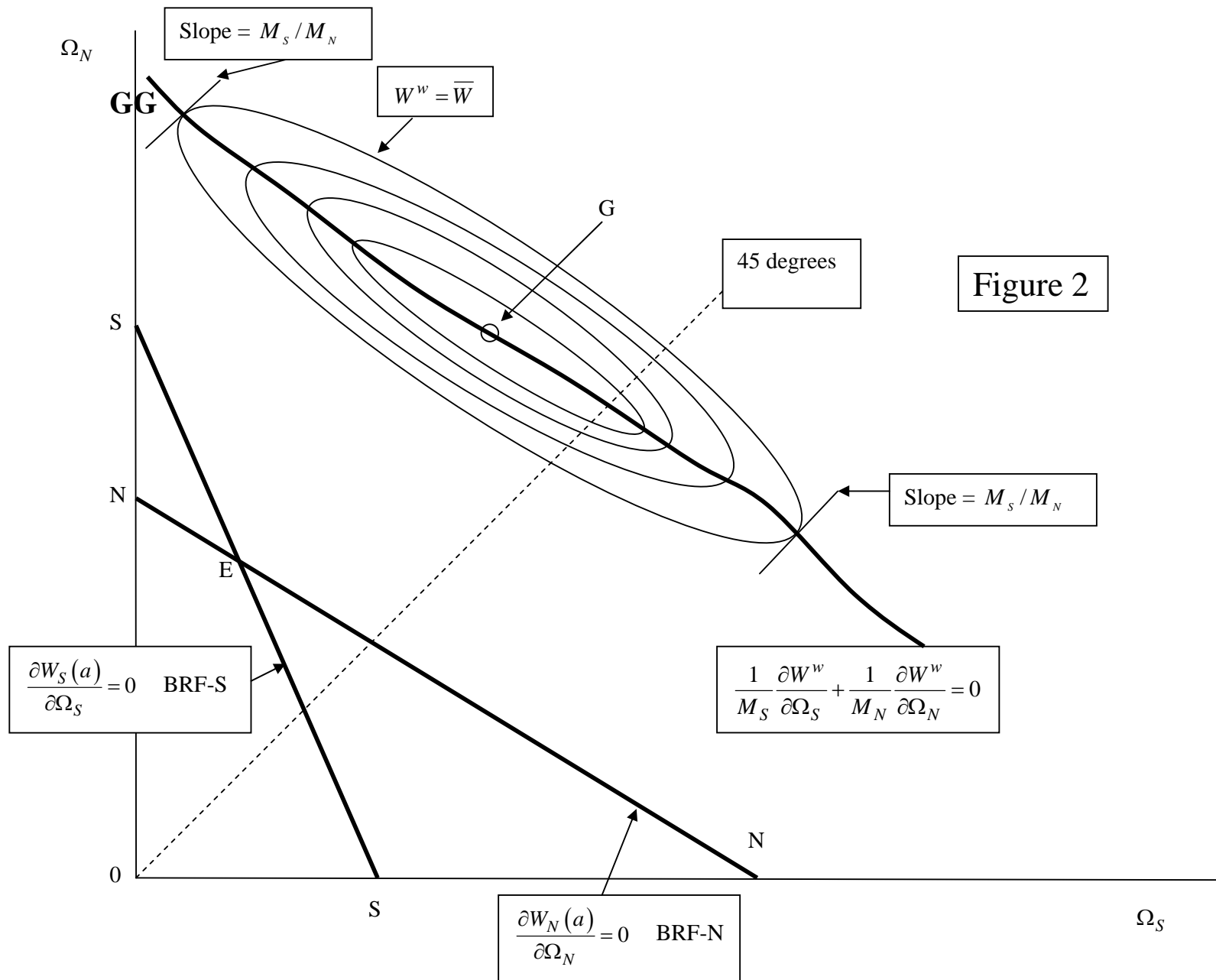
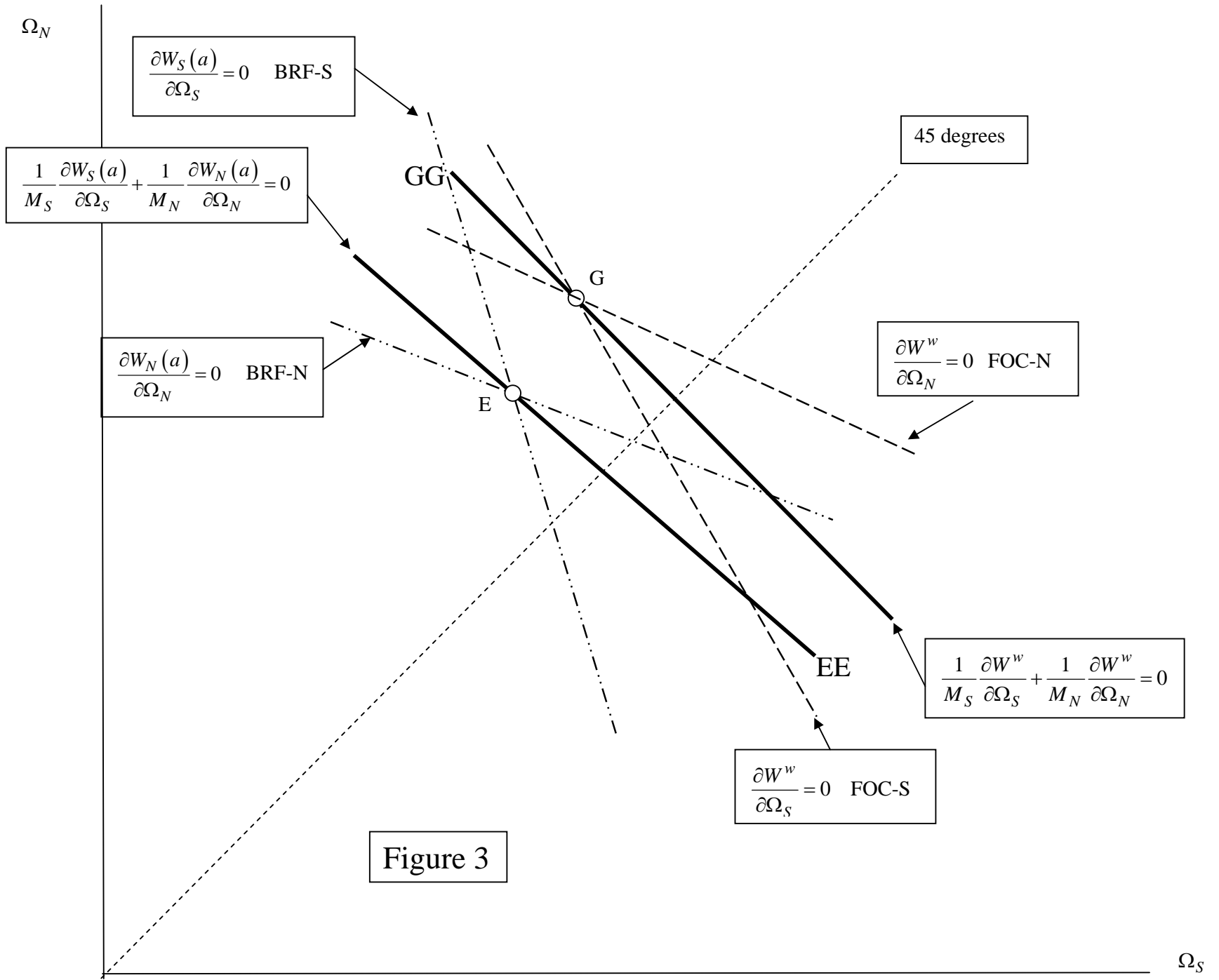


Figure 1





Country	phi	M	M*phi
US*	51,510	1772986841	9.13266E+13
Japan	27,044	1170193555	3.1647E+13
Germany	8,065	562757898.1	4.53836E+12
France	3,310	367990558.4	1.21805E+12
UK	3,042	284028686.2	8.63944E+11
Canada	2,703	148452725	4.01268E+11
South Korea	2,551	134158352.1	3.42271E+11
Italy	1,379	267299074.1	3.68472E+11
Switzerland	1,190	70095671.69	83396325393
Sweden	1,087	58760190.1	63857636591
Netherlands	1,020	103945394.5	1.05998E+11
Israel	629	23996319.16	15087685672
Australia	594	97579663.7	57986715154
Belgium	586	67683862.59	39662743478
Finland	535	34152319.22	18271490783

Country	phi	M	M*phi
Austria	401	57205259.87	22925007893
Denmark	363	43703971.46	15875467633
Spain	201	153705026.3	30894710286
Norway	176	36790975	6466013856
South Africa	109	45820999.24	5005944167
New Zealand	91	16018494.14	1461687590
Ireland	80	20069625.78	1600552656
Brazil	73	202314883.7	14667829068
India	70	142688343.3	9952511945
China	68	281883387.7	19027128670
Mexico	54	92621183.25	5024699191
Hungary	39	13699371.49	537700331
Argentina	38	76182172.99	2894922574
Luxembourg	21	4776349.948	97915173.93
Greece	17	32270403.53	556664460.9
SUM	107,044	6383831559	1.31227E+14

Table 1: Data on M and phi

M is the average value of consumption (or absorption) per year in US dollars of patent-sensitive goods in the country in the year 1996-1999

phi is the average number of patents granted to residents of the country per year by the US Patent Office in the years 1996-1999

*US figure for phi is adjusted for home-bias effect as discussed in the text