Free Trade and Protection of Intellectual Property Rights:

Can we have one without the other?*

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Abstract

This paper is concerned with the interaction between trade policies and the protection of Intellectual Property Rights (IPRs). In particular, it investigates the welfare implications of an international agreement on one or both policy instruments. The main insights are first, that both sets of policies are substitutes and second, that they are affected by the same Prisoner's Dilemma problem. As a consequence, an agreement in *both* policy instruments is needed to achieve any positive welfare gains, which supports the long standing claim of policy makers from developed countries that protection of IPRs should be included in multilateral trade agreements.

Key words: Trade policy; Intellectual Property Rights; International agreements

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I. Introduction

Economists have long extolled the virtues of free trade. Besides the static welfare gains from specialization according to comparative advantage, it has been argued that trade generates dynamic gains by facilitating international knowledge spillovers, reducing research redundancy and providing access to a wider range and cheaper intermediate and capital goods[1]. These theoretical arguments are further supported by an impressive body of empirical evidence.[2] Yet, despite the significant reduction in worldwide tariff levels achieved through several rounds of multilateral trade negotiations under the General Agreement on Tariffs and Trade (GATT), many barriers to trade still exist in the world trading system. Especially worrying for supporters of the free trade cause is the breakdown of the recent attempt to launch a new round of multilateral trade negotiations under the World Trade Organization (WTO) at the Seattle meeting. Arguably, one of the main reasons for the slowdown of trade negotiations is the growing lack of consensus between developed and developing countries on the agenda of the negotiations. Indeed, ever since the Uruguay Round of GATT, developed countries have tried to push many issues on the agenda on the grounds that these issues were "trade related". Of these issues, only a few, most notably the protection of Intellectual Property Rights (IPRs), have led to the signature of an agreement in the context of multilateral trade negotiations. Yet, even as far as the protection of IPRs is concerned, no theoretical consensus has been reached as to whether and how its exclusion from the agenda of trade negotiations

[1] For seminal contributions see Ethier (1982), Rivera-Batiz and Romer (1991), Grossman and Helpman (1991a) and (1991b). For more recent works see e.g. Baldwin and Seghezza (1996), Van and Wan (1997), Goh and Olivier (2001).
[2] See for examples, Harrison (1995), Frankel and Romer (1999) and Bayoumi et. al. (1999).

could constitute an impediment to freer trade. With this gap in the trade literature, it is even more difficult to assess whether other more controversial issues such as labor and environmental standards are "trade-related". The objective of this paper is to fill this gap and to answer the question as to whether and why the protection of IPRs constitutes a "trade-related" issue.

IPRs protection was added to the agenda of the Uruguay Round of GATT negotiations at the request of the developed countries in 1986. At that time, IPRs were under the jurisdiction of the World Intellectual Property Organization (WIPO), a UN agency that overseas the international agreements on IPRs such as the Paris Convention (on patents) and the Berne Convention (on copyrights). The Paris Convention required member states to apply identical criteria to foreign and domestic firms, but did not prescribe specific levels of patent protection. The fact that IPRs protection varied widely across countries led developed countries to seek an international agreement on IPRs protection under GATT, on the grounds that weak protection of IPRs distorts natural trading patterns and acts as an impediment to free trade. An agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs) was finally concluded in Marrakesh in 1994. Under the TRIPs agreement member countries are required to provide for and to enforce certain minimum standards of IPRs protection. Members' compliance with the agreement is monitored by a TRIPs Council and dispute settlement takes place under the WTO dispute settlement procedures.

The policy debate about TRIPs motivated several careful analyses of the implication of IPRs protection for innovation and welfare. Chin and Grossman (1988) analyzed a model whereby all innovation takes place in the North and all imitation takes place in the South and found that it is generally not in the interest of the South to protect Northern intellectual property. Diwan and Rodrik (1991) assumed that the South differs from the North in their preference for certain technologies and showed that the South may want to protect Northern intellectual property to facilitate the invention of technologies appropriate to the South. Finally, Helpman (1993) pointed out in a general equilibrium model that it is possible for Northern innovation to slow down with stricter IPRs protection in the South and that stricter IPRs protection may hurt both the North and the South. However, all these paper share a common denominator in that they all cast their analyses under the assumption of *free trade* in the goods market. Hence, they can examine only the desirability of IPRs protection *per se* and not whether IPRs protection is a "trade-related issue". To address that question indeed, we believe that it is necessary to cast the analysis in a world where trade regimes are endogenous. In other words, we need a model where countries choose optimally *both* the level of IPRs protection and the level of trade barriers.

We investigate the issue in a multi-country dynamic general equilibrium model where growth is driven by product innovation. Each country has a research sector and a manufacturing sector. The manufacturing sector produces goods invented by the local research sector. Consumers are assumed to have a "preference for variety". Each country exercises a choice over the level of tariffs to impose on imports as well as the stringency of IPRs protection to grant to innovators, both home and foreign. On the one hand, lower IPRs protection and higher tariffs both reduce the profits of firms and hence the innovation rate at the equilibrium. On the other hand, lower IPRs protection implies lower prices of goods while higher tariffs implies higher lump sum transfers from tariff revenue, both of which increase real expenditure of consumers. We show the existence of a Prisoner's Dilemma in the setting of optimal IPRs and tariff policies; while world welfare is maximized when all countries enforce maximum patent protection and practice free trade, individual countries have incentives to free ride on other countries by lowering patent protection and/or impose trade tariffs. We also show that these incentives are increasing in the number of countries in the world. More importantly, we show that tariffs and patent protection are substitute policies. The implication is that even if countries sign a binding agreement fixing the level of one policy instrument, countries have the incentives and the possibility to change the policy instrument that is at their free disposal to reach the same equilibrium allocation as they would get without any international agreement. Only cooperation on *both* policy instruments solves the Prisoner's Dilemma problem and is Pareto improving. The conclusion is that countries have no incentives to enter a trade agreement unless there is also an agreement on IPRs protection. Thus, the model adds direct support to the claim by developed countries that the failure to enforce minimum international standards in IPRs protection acts as a barrier to further trade liberalization.

This paper is not alone in looking at the impact of domestic policies on the outcome of multilateral trade agreements. Copeland (1990) first showed that trade agreements can be beneficial even if there exist other policy instruments which are non-negotiable. More recently a very active strand of literature has focused on the desirability of including labor and environmental standards on the WTO agenda (see e.g. Bhagwati and Hudec 1996 or Bagwell and Staiger 1999). Our analysis shares some common factors with this literature, most notably the modeling of trade policy as a multi-stage game between governments. However, an important difference is that our analysis is cast in a dynamic general equilibrium framework while the existing literature has restricted itself to a static analysis. This feature of our model is necessary for our purposes, as one can hardly discuss IPRs protection policies without considering their impact on innovation and growth. In addition, our model allows us to discuss the dynamic effects of multilateral trade agreements, which complements the existing literature.

The rest of the paper is organized as follows. In section II, we set up the model. In section III we derive optimal tariffs and patent protection and compare the welfare levels under a) binding international agreements in both policy instruments, b) no binding agreement in either policy instrument and c) binding international agreement in one policy instrument. Section IV concludes.

II. The Model

We consider a world populated by N symmetric countries. Total world population is constant over time and of measure 1. Each country produces a range of final consumption goods invented by local researchers and all goods are tradable. The range of goods produced in each country increases over time through investment in R&D. There is no uncertainty in the R&D process. The utility function of a representative household in each country is of the Dixit-Stiglitz type, exhibiting a taste for variety. There is only one primary factor, labor, that can be used to undertake research or to produce goods. Each country exercises a choice over the level of tariffs and patent protection to implement.

In this section we solve for the balanced growth path given the level of tariffs and patent protection. We solve for optimal policies in the next section.

Households

In each country there exists a measure 1/N of identical households. Households are infinitely lived and are endowed with a constant flow of labor L. They can borrow or lend freely at the instantaneous, risk-free, interest rate r(t). Following Grossman and Helpman (1991b), the representative household in each country i maximizes the intertemporal utility:

$$U_i(t) = \int_t^{\infty} e^{-\rho(\tau-t)} \log D_i(\tau)\, d\tau, \qquad (1)$$

subject to the usual intertemporal budget constraint. ρ is the subjective discount rate and $D_i(t)$ represents an index of consumption at time t.

We adopt for D the Dixit and Stiglitz (1979) specification that imposes the same constant elasticity of substitution between any pair of goods. Specifically,

$$D_i(t) = \left[\int_0^{m(t)} (y_{ij})^{\gamma}\, dj\right]^{\frac{1}{\gamma}}, \qquad 0 < \gamma < 1, \qquad (2)$$

where y_{ij} denotes consumption of design j by a household in country i and [0,m(t)] is the range of final products existing in the world at time t.

Let E_i denote total expenditure of all households in country i. Since each country has a measure 1/N of identical households, the expenditure of one household is given by NE_i.[3] Given that all firms from the same country j charge the same price p_{ij} to consumers in country i, it is straightforward to show that each household in country i maximizes its instantaneous utility by purchasing:

$$y_{ij} = \frac{NE_i p_{ij}^{-\varepsilon}}{\sum_{k=1}^{N} m_k(t) p_{ik}^{1-\varepsilon}}, \tag{3}$$

units of design j, where p_{ij} is the price of good design j sold in country i, $m_k(t)$ is the cumulative number of varieties invented by agents in country k at time t, with $m(t) \equiv \sum_{k=1}^{N} m_k(t)$, and $\varepsilon = \frac{1}{1-\gamma} > 1$ is the elasticity of substitution between any two products.

It is well known that the solution to the consumer problem satisfies:

$$\frac{\dot{E}_i(t)}{E_i(t)} = r_i(t) - \rho \,. \tag{4}$$

where $r_i(t)$ is the prevailing market interest rate in country i.

Without loss of generality, we normalize prices so that at any time t:

$$\sum_{i=1}^{N} E_i(t) = 1 \tag{5}$$

We finally assume that there is perfect international capital mobility, which implies that the interest rate must equalize across countries. This together with equation (5) implies that:

$$r_i(t) = \rho \qquad \text{for all i and t.} \tag{6}$$

[3] We keep the world population constant as we vary the number of countries so that our results are not affected by the scale effect associated with the type of endogenous growth model we use in this paper.

Production

Each country has a manufacturing and a research sector. New good designs are created in the research sector and then produced in the manufacturing sector. For simplicity, we assume that the inventor of a good design must necessarily locate the production of that design in his own country. However, as will be made clear later on in the paper, the design may also be produced by foreign imitators. We choose units so that each unit of consumption good is produced using one unit of labor.

The number of good designs produced in each country can be increased by undertaking research, which uses labor as its sole input. Following Romer (1990) we assume that the productivity of a researcher increases as the society accumulates more ideas, represented by the number of products previously invented. We assume that knowledge spillovers are international in scope so that researchers in each country benefit from knowledge accumulation in all the other countries in the world. Also, as long as no country pursues an autarky policy, there will be no duplication of research effort since it is always more profitable to invent a unique product (Rivera-Batiz and Romer 1991). The production function in the research sector is thus given by:

$$\frac{\dot{m}_i(t)}{m(t)} = A\ L_i^R \tag{7}$$

Trade Policy

We assume that all goods produced are tradable and that there is no transport cost. The government in each country i can choose the level of *ad valorem* tariff τ_i to impose on imports. If the external price is q, then domestic consumers face a price equal to $(1+\tau_i)q$. In the absence of prohibitive tariffs, all goods produced abroad will be imported since consumers' utility function exhibits a taste for variety. We make the following assumption regarding tariff policy.

Assumption 1

Tariffs are set at time 0 and remain constant through time.

Assumption 1 is a natural assumption to make since in this paper, we concern ourselves with stationary equilibria only. We make the assumption so as to abstract away from the possibility of dynamic games between the two countries.[4]

Intellectual Property Rights Protection

We assume that the government in each country can exercise a choice over the type of patent protection to be granted to any innovator who files for the protection.[5] An innovator of a product has to file for patent protection in every country in which the good is being sold since the enforcement of the patent lies within the jurisdiction of the consuming country. Also we assume that the same protection applies to all sales within a country, regardless of whether the sales originate from foreign or domestic firms.[6] Once granted the patents, the innovator can either produce and sell the good on his own or sell the patents to another domestic firm, which then becomes the exclusive producer of the invented product. We assume that there are a large number of firms that bid for the patents so that regardless of the option chosen by the innovator, he will eventually get all the profits generated by his patents. Since each variety of consumption good can be sold in all the countries, the profits of each

[4] See Fudenberg and Tirole (1991), chapter 5, p. 145-203.
[5] In this paper we use the term "patent protection" and "IPRs protection" interchangeably as patent protection is the type of protection of relevance for industrial innovation.
[6] This is consistent with the TRIPs agreement in WTO and the Paris Convention. We leave the analysis

innovator and hence the incentive to innovate will depend on the patent protection granted by all the countries combined.

In general, there are two dimensions on which the patent protection could operate: patent length and patent breadth. In this paper we assume that the patent once granted is infinitely-lived. This assumption can be defended on three grounds. First, Gilbert and Shapiro (1990) showed in a partial equilibrium setting that infinite patent length generally is socially optimal and that the appropriate margin on which patent policy should operate on is patent breadth. Second, empirical evidence shows that, most of the time, patents are infringed upon or become obsolete long before the end of their legal life (e.g. Mansfield, 1984 and 1985). This suggests that patent breadth and stringency of enforcement are the dimensions of patent protection that matter the most in practice. Third, the assumption of infinite patent length allows us to address the questions we pose in this paper in a very tractable manner.

Since the patent life is infinite, the amount of protection granted by the patent and, thus, the amount of profits reaped by the innovator, solely depend on the patent breadth[7]. Patent breadth matters as we assume the existence of a competitive sector in each country that can locally imitate existing good designs at a constant per unit cost of imitation. Thus, the optimal pricing strategy of a patentee in a given market is to charge a price no larger than the cost of imitation of the competitive fringe in that market in order to discourage potential imitators from competing with his product[8]. The cost of imitation is in turn determined by the strictness of prevailing patent laws

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of asymmetric protection to future work.

[7] In this paper, we take "patent breadth" to mean both patent breadth *per se* and the stringency with which the patent laws are enforced.

[8] Hence, there is no production by the competitive sector at the equilibrium.

and enforcement. Smaller breadth of protection reduces the (technical or legal) costs of imitation and hence the price received by the innovator.[9] Thus, as in Gilbert and Shapiro (1990)[10], we may parametrize the patent breadth by the maximum price that the innovator can charge under the protection of the patent:

Definition 1: Let $\bar{\mu}$ be the monopoly mark-up for each variety of consumption good and w_i be the wage rate in country i. We say that country i implements a patent breadth equal to $b_i \in [0, 1]$ iff the maximum price that firms can charge to consumers in country i is equal to $w_i (1 + b_i \bar{\mu})$.

We define $\mu_i \equiv b_i \bar{\mu}$. (8)

Assumption 2

Patent breadths are set at time 0 and remain constant over time.

To rephrase Definition 1, a patent breadth of 0 corresponds to the case where the competitive fringe can imitate and produce at the same unit cost as the patentee. A positive patent breadth implies that the unit cost of the competitive fringe is greater than one (in terms of labor units) and hence the patentee is able to charge a price higher than its unit cost, which allows him to earn a positive profit to cover the cost of innovation. For convenience, we assume that the maximum patent protection possible (b=1) implies a unit cost of imitation such that the innovator firms are able to charge the monopoly mark up in the absence of tariffs.[11] In the presence of tariffs, foreign

[9] We can think of patent breadth either as affecting the additional unit costs, which the imitators need to incur to add extra features to the product so as to avoid infringing on the patent, or as affecting the (expected) unit costs incurred by the imitators if they are brought to court and successfully prosecuted.
[10] See also Diwan and Rodrik (1991) and Goh and Olivier (2002).
[11] In reality, patent protection never provides for full monopoly (Diwan and Rodrik, 1991).

firms' mark up is strictly less than the monopoly mark up. The assumption that patent breadths are set at time 0 and remain constant over time is again made so as to avoid dynamic games between countries.

Having described the trade and IPRs regimes, we now solve the firm's problem.

Firms

Given the consumers' preference, each innovator firm faces a demand function for its product given by equation (3) in every country. Since there is a continuum of varieties of final consumption goods, each firm chooses its price taking the denominator of equation (4) as constant. It is straightforward to show that the monopoly mark-up is:

$$\bar{\mu} = \frac{1-\gamma}{\gamma} \tag{9}$$

Each innovator firm from country i solves the following problem:

$$\underset{\{p_{1i},p_{2i},\ldots.. p_{Ni}\}}{\text{Max}} \left\{ \sum_{j\neq i}^{N} \frac{E_j p_{ji}^{-\varepsilon}}{\sum_{k=1}^{N} m_k p_{jk}^{1-\varepsilon}} \left[\frac{p_{ji}}{1+\tau_j} - w_i \right] + \frac{E_i p_{ii}^{-\varepsilon}}{\sum_{k=1}^{N} m_k p_{ik}^{1-\varepsilon}} [p_{ii} - w_i] \right\} \tag{10}$$

$$\text{s.t. } p_{ji} \leq w_j(1+\mu_j) = w_j\left[1+\frac{b_j(1-\gamma)}{\gamma}\right]$$

where p_{ji} is the price charged by country i's innovator firms in country j.

We show in the appendix[12] that for any set of tariff and IPRs protection policies (τ_1, ...,τ_N; b_1, ..., b_N), equilibrium wages are such that $b_j \leq 1$ implies that the constraint in (10) is binding. The solution to (10) is thus given by:

$$p_{ji} = p_{jj} = (1+\mu_j)w_j \tag{11}$$

Equation (11) implies that all firms (home and foreign) charge the same price in any given country j. Substituting (11) into the demand function (3), we find that the equilibrium output of each domestic firm in country i is given by:

$$x_i = \sum_{j=1}^{N} \frac{E_j}{m(1+\mu_j)\, w_j} \tag{12}$$

Hence each firm earns an instantaneous profit of:

$$\pi_i = \sum_{j\neq i} \frac{E_j}{m\,(1+\mu_j)w_j}\left[\frac{(1+\mu_j)w_j}{1+\tau_j} - w_i\right] + \frac{E_i}{m\,(1+\mu_i)w_i}\left[(1+\mu_i)w_i - w_i\right] \tag{13}$$

and a discounted value of profits of:

$$V_i(t) = \int_t^{\infty} e^{-\rho(\tau-t)}\, \pi_i(\tau)d\tau \tag{14}$$

Substituting (6) and (13) into (14), we get the discounted value of profits as a function of patent breadth and tariffs:

$$V_i(t) = \frac{1}{m(t)\,(\rho+g)}\left[\sum_{j=1}^{N} \frac{E_j}{(1+\tau_j)w_j} - \sum_{j=1}^{N} \frac{E_j w_i}{(1+\mu_j)w_j} + \frac{\tau_i E_i}{1+\tau_i}\right] \tag{15}$$

where g is the rate of expansion of consumption good varieties in the whole world.

In each country i, firms may enter freely into R&D. Given the production function of R&D (7), each new design requires a cost of w_i / (Am) for its invention. Each new

[12] See the end of the proof of Proposition 1.

invention generates a discounted value of profits given by (15). Free entry together with constant returns to scale in research imply that the cost of inventing a new design must be at least as large as the discounted value of profits. Hence, we have:

$$\frac{w_i}{Am} \geq \frac{1}{m(t)\,(\rho+g)}\left[\sum_{j=1}^{N}\frac{E_j}{(1+\tau_j)w_j} - \sum_{j=1}^{N}\frac{E_j w_i}{(1+\mu_j)w_j} + \frac{\tau_i E_i}{1+\tau_i}\right], \qquad (16)$$

with equality whenever $g_i > 0$, where g_i is the rate of innovation in country i.

We impose the following restriction on parameters to guarantee that there exists at least one set of tariffs and patent breadths such that the rate of innovation is positive:

<u>Assumption 3</u>

$$AL\,(1-\gamma) > \gamma\rho \qquad (17)$$

We are now ready to compute the equilibrium. In this paper, we focus on balanced growth paths, that is, on competitive equilibria such that the rate of innovation g is constant over time and across countries. The derivation of a balanced growth path with positive innovation rate are fairly standard is delegated to the Appendix. We summarize the main features of the equilibrium in the following proposition:

<u>Proposition 1</u>

Given a set of tariffs (τ_1, ...,τ_N) and a set of patent protection (b_1, ..., b_N), there exists a unique balanced growth path with positive innovation iff:

$$\frac{AL}{(\rho+AL)} \geq \sum_{i=1}^{N}\frac{\gamma}{(\gamma+b_i(1-\gamma))}\frac{1+\tau_i}{N+\tau_i}$$

Furthermore, the level of real expenditure of each country and the world innovation rate at the equilibrium are given respectively by:

$$D_i(t) = \left(\frac{\rho}{A} + L\right)\frac{N(1+\tau_i)}{N+\tau_i}\,\frac{\gamma}{\gamma + b_i(1-\gamma)}\, m(t)^{\frac{1-\gamma}{\gamma}} \tag{18}$$

$$g = AL - \sum_{i=1}^{N} \frac{\gamma(\rho + AL)}{(\gamma + b_i(1-\gamma))}\frac{1+\tau_i}{N+\tau_i} \tag{19}$$

Proof: See Appendix.

Proposition 1 characterizes the equilibrium growth rate and the equilibrium real expenditures as a function of the level of patent protection and of tariffs. A notable implication of Proposition 1 is that countries can raise the level of real expenditure of their consumers either by increasing tariffs or by lowering patent protection. This is because higher tariffs transfer income from the rest of the world to the local consumers while lower patent protection reduces the monopoly power of firms and hence allow consumers to purchase goods at a lower price. However, raising tariffs and lowering patent protection also have an adverse effect on innovation rate since, in either case, firms earn less profits and hence have less incentives to innovate. This trade-off will play a central role in the analysis of optimal policies in the next section. Also note that the maximum innovation rate is obtained when all tariffs are 0 and all patent breadths are 1. The requirement that this maximum innovation rate is positive provides the restriction on parameters given by Assumption 3.

III International Cooperation in Trade Policy and IPRs Protection

In this section, we solve for the optimal tariffs and patent breadths for each country and analyze the welfare implications of international cooperation in trade and/or IPRs protection policies. We first derive optimal policies when countries engage in binding international agreements in the setting of both tariff and patent protection policies and then compare them to the case where there is no international cooperation in either policy. Finally, we analyze the cases where there is a binding international agreement in only one policy instrument.

Binding International Agreements in both Tariff and Patent Protection

We first solve for the optimal common tariff and patent protection in each country given that countries choose to abide by international agreements on both tariffs and patent protection. In the presentation of our results, we assume that countries choose the common tariff level first and then the common patent protection. However, it can easily be shown that reversing the timing of the setting of policies does not change the results. We solve for the optimal policies by backward induction, first solving for optimal patent protection given the level of tariffs and then solving for the optimal level of tariffs given the optimal level of patent protection.

The utility of a representative agent in country i at the equilibrium is given by:

$$U_i(\bar{\tau},\bar{b}) = \frac{1}{\rho}\log\left[\left(\frac{\rho}{A}+L\right)\frac{1+\tau_i}{N+\tau_i}\frac{\gamma}{\gamma+b_i(1-\gamma)}\right] + \frac{(1-\gamma)}{\gamma}\frac{\log m(0)}{\rho} + \frac{(1-\gamma)}{\gamma\rho^2}g(\bar{\tau},\bar{b}) \tag{20}$$

where (20) is obtained from substituting the equilibrium level of real expenditures (18), into equation (1). $\bar{\tau}$ and $\bar{b}$ represent the vector of tariffs and patent breadths, respectively and $g(\bar{\tau},\bar{b})$ is given by equation (19).

Equation (20) has a nice interpretation in that the representative agent derives utility from two sources - quantity and variety. The first two terms represent agents' utility derived from the level of real expenditure while the last term represents the utility derived from the increase in the variety of goods. As mentioned above, higher tariffs (lower patent protection) increase real expenditure but reduce the innovation rate. There are therefore two opposing effects of tariffs or patent protection on welfare. Given the two opposing effects on welfare, optimal tariffs or patent protection depend on which of the two effects dominate. The optimal tariff and patent protection is found by maximizing (20) with respect to patent protection and then tariff, given that the same levels of tariff and patent protection apply to all countries. We solve the maximization problem in the appendix and summarize our results in the following proposition:

Proposition 2

In a symmetric equilibrium with all countries engaging in binding international agreements in both tariff and IPRs protection, free trade and maximum patent protection are optimal.

Proof : See Appendix

The intuition for the result in Proposition 2 is that with cooperation in both policy instruments, the multi-country problem reduces to that of a single closed economy model with tariffs acting as taxes on firms' profits. It is well known that there is too little innovation at the equilibrium of economies where endogenous growth is driven by expansion in product variety (Romer 1990, Grossman and Helpman 1991b).

Hence, since the range of possible tariffs is assumed to be bounded below by 0 and the range of patent protection bounded from above by 1, it is optimal to set tariffs to 0 and patent breadth to 1.

No International Agreement on Either Policy

We now analyze the case where countries are bound by no international agreement on either tariff or patent protection level. All countries choose tariff and patent protection simultaneously. We solve for the subgame perfect Nash equilibria. As before, we assume that the level of tariff is chosen first before patent protection, but we can easily show that the same equilibrium allocations are achieved if patent breadth is chosen first. We obtain the following proposition:

Proposition 3

In a symmetric equilibrium without international cooperation, we have either:

i) g=0

or:

ii) Optimal tariffs and patent protection are indeterminate. A necessary and sufficient condition for a pair of policies (τ^u, b^u) to be optimal is:

- $\tau^u \leq \dfrac{N\rho - (1-\gamma)(\rho + AL)}{(1-\gamma)(\rho + AL) - \rho}$

and:

- $\dfrac{(\rho + AL)}{\rho} - \dfrac{\gamma}{1-\gamma} - \dfrac{(\rho + AL)}{\rho}\dfrac{N-1}{N+\tau^u} - b^u = 0$

Equilibrium allocations are the same for each of the (τ^u, b^u) above and the equilibrium growth rate is given by:

$$g = AL - \frac{N\gamma\rho}{1-\gamma}$$

Proof: See Appendix

Corollary 1

A necessary condition for g>0 is $N < \frac{1-\gamma}{\gamma\rho} AL$.

An important implication of Proposition 3 is that keeping the tariff level fixed, the level of optimal patent protection decreases as the number of countries in the world increases. Similarly, keeping patent protection fixed, the optimal level of tariff increases as the number of countries increases. These results are due to the individual country's incentive to free ride on other countries in the provision of incentives for innovation. As the number of markets increases, each market's contribution to firms' profits decreases and hence each individual country's policies have less impact on the rate of innovation. Since lower IPRs protection and/or higher tariffs increase real expenditure of domestic consumers, individual governments have higher incentives to lower IPRs protection and/or raise tariffs. The final implication of the free riding problem is given in Corollary 1: if the number of countries in the world is large enough, there can be no growth at the non-cooperative equilibrium.

The existence of a free riding problem in IPRs protection has been pointed out elsewhere in the literature but in a North South context whereby the South, which imitates and does not innovate, free rides on Northern innovations. (See e.g. Diwan and Rodrik 1991 and Yang 1998). In this paper we show that the free riding problem is not confined to the Southern countries but can also affect Northern countries. In addition, we show that a free riding problem applies to tariff protection as well. That a free riding problem arises also with respect to tariff policy has so far not been recognized in the existing literature. In fact, contrary to the optimal tariff literature where the optimal level of tariff gets smaller for smaller economies (Gros 1987), this paper shows that the incentive to free ride leads to higher level of optimal tariff as a country gets smaller. The intuition for this result is that when the number of countries in the world is small, the dynamic losses from a lower rate of innovation resulting from the imposition of a tariff outweigh the gains from a better terms of trade. But as the number of countries gets larger, free riding kicks in and the terms of trade gains increasingly outweigh the dynamic losses from a lower rate of innovation, thus raising the incentive to impose higher tariffs. This free riding problem may explain why countries pursue free trade agreements within a more limited set of countries (that is, regionalism) rather than relying solely on multi-lateral trade agreements (multilateralism) as for the latter, the free riding problem is more severe and agreements are harder to reach.

However, the main result in Proposition 3 is the multiplicity of optimal tariffs and patent protection policies. Both high and low tariffs are consistent with the non-cooperative equilibrium as countries can "compensate" a lower level of tariffs by a lower level of patent protection so as to achieve their optimal level of free-riding on other countries. Note that this result does not mean that IPR protection and tariffs are equivalent policies in the same sense as tariffs are equivalent to a combination of consumption tax and a production subsidy which provides the same incentives to every agent in the economy. Indeed, under non-discrimination, IPRs protection policies apply equally to local and foreign firms alike while tariffs affect only foreign firms. However, Proposition 3 shows that *at the equilibrium*, after prices and wages have adjusted, the same allocations are obtained for a low tariff/low IPRs protection as for a high tariff/high IPRs protection regime. The next section deals with the impact of this substituability feature on the desirabilty of multilateral trade agreements.

Binding International Agreement in One Policy Instrument

In this section, we assume that all the countries in the world agree to abide by a common level of IPRs protection while retaining the freedom to set tariff level. We also assume that countries first agree on the common level of patent protection and then they decide on the level of tariff.[13]

We again solve for the equilibrium in the appendix and summarize our results by the following proposition:

Proposition 4

In a symmetric equilibrium with positive innovation and with binding international agreement on patent protection only, the welfare of each country is the same as the equilibrium with no international cooperation.

Proof : See Appendix

Proposition 4 states that there are no welfare gains if countries cooperate on only one policy instrument. The intuition is that tariffs and patent protection are substitute policies in the sense that they can both be used to increase real expenditure and reduce

[13] This is a natural timing for the setting of the two policies since countries can always re-optimize after

innovation rate. In the equilibrium without any binding international agreement, each country decides on the optimal trade-off between increasing real expenditure and reducing innovation rate even though there are two policy instruments to achieve this optimal trade-off. If patent protection is fixed by international agreement, each country is still free to choose the level of tariff so as to attain the optimal trade-off. For instance, when countries cooperate to increase patent protection, each country then has the incentive to increase its tariffs to increase real expenditure and reduce innovation rate back to the equilibrium without cooperation in patent policy. Therefore, international cooperation in patent protection results in no welfare gain compared to the non-cooperative equilibrium. There is no incentive for countries to cooperate on IPRs protection unless there is an international agreement on tariffs reduction at the same time.

In a similar manner and as stated in the following proposition, we can show that there is no welfare gain if countries cooperate on a common level of tariffs but not patent protection. There is therefore no incentive for countries to reach international agreements on tariff reduction unless an agreement on IPRs protection could be achieved at the same time.

Proposition 5

In a symmetric equilibrium with positive innovation and with binding international agreement on tariff level only, the welfare of each country is the same as the equilibrium with no international cooperation.

Proof: See Appendix.

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the agreement on IPRs protection.

Putting Propositions 2-5 together, we conclude that the absence of a multilateral agreement on IPRs protection can indeed act as a hindrance to countries' willingness to agree on further trade liberalization. Furthermore, welfare gains from cooperation in IPRs protection can be achieved only if it is combined with an international agreement on trade policy.

IV Conclusion

In this paper we argued that further progress in trade liberalization cannot be achieved without international efforts in coordinating IPRs protection. Furthermore, even though there are welfare gains from international cooperation in IPRs protection due to the free riding problem, such gains will not accrue unless there is international cooperation in trade policy at the same time. Without simultaneous international efforts in trade and IPRs policies cooperation, countries have the incentive to change the policy instrument still at their disposal in such a way as to nullify any welfare gains that may accrue with international cooperation in the other policy instrument. While these results are rather extreme due to the stylized nature of the model, it seems clear that the basic insight regarding the substitutability of trade and IPRs policies, and therefore regarding the substantial welfare gains attainable with cooperation on both policy instruments instead of one, would carry through in most models. Our conclusion is that the long standing claim of policy makers from developed countries that weak or nonexistent IPRs protection acts as a barrier to free trade was indeed correct.

Appendix

Proof of Proposition 1

With positive innovation rate in all countries we have from (16):

$$\frac{w_i}{Am(t)} = \frac{1}{m(t)\,(\rho+g)}\left[\sum_{j=1}^{N}\frac{E_j}{(1+\tau_j)} - \sum_{j=1}^{N}\frac{E_j w_i}{(1+\mu_j)w_j} + \frac{\tau_i E_i}{1+\tau_i}\right] \tag{A1}$$

and

$$\frac{w_k}{Am(t)} = \frac{1}{m(t)\,(\rho+g)}\left[\sum_{j=1}^{N}\frac{E_j}{(1+\tau_j)} - \sum_{j=1}^{N}\frac{E_j w_k}{(1+\mu_j)w_j} + \frac{\tau_k E_k}{1+\tau_k}\right] \tag{A2}$$

for any pair of countries i and k.

Eliminating the innovation rate g from (A1) and (A2) we get:

$$\frac{1}{w_i}\left[\sum_{j=1}^{N}\frac{E_j}{(1+\tau_j)} + \frac{\tau_i E_i}{1+\tau_i}\right] = \frac{1}{w_k}\left[\sum_{j=1}^{N}\frac{E_j}{(1+\tau_j)} + \frac{\tau_k E_k}{1+\tau_k}\right] \tag{A3}$$

At the equilibrium, the expenditure of each country is equal to income received, that is, the sum of capital income, labor income and tariff revenue. Capital income at time t in country i is equal to $r_i(t)W_i(t)$, where $W_i(t) \equiv m_i(t)V_i(t)$. From (6), (15) and (A1) we get:

$$E_i = \frac{m_i w_i \rho}{Am} + w_i\frac{L}{N} + \sum_{j\neq i} m_j \frac{E_i}{m(1+\mu_i)w_i}\frac{\tau_i(1+\mu_i)w_i}{1+\tau_i} \tag{A4}$$

or:

$$\frac{E_i}{w_i} = \frac{\dfrac{L}{N}+\dfrac{\rho m_i}{Am}}{\dfrac{1}{(1+\tau_i)}+\dfrac{\tau_i}{(1+\tau_i)}\dfrac{m_i}{m}} \tag{A5}$$

From (12) and the assumption of unit labor cost, the total demand for labor in manufacturing sector is given by:

$$L_i^M = m_i \sum_{j=1}^{N} \frac{E_j}{m(1+\mu_j)w_j} \tag{A6}$$

From (A1) and (8), the demand for labor in research is given by:

$$L_i^R = \frac{m_i}{w_i m}\left[\sum_{j=1}^{N} \frac{E_j}{(1+\tau_j)} - \sum_{j=1}^{N} \frac{E_j w_i}{(1+\mu_j)w_j} + \frac{\tau_i E_i}{1+\tau_i}\right] - \frac{\rho m_i}{Am} \tag{A7}$$

The labor market clearing condition is:

$$\frac{L}{N} = L_i^M + L_i^R \tag{A8}$$

Substituting (A6) and (A7) into (A8) we have:

$$\frac{L}{N} = \frac{m_i}{m}\left[\sum_{j=1}^{N} \frac{E_j}{(1+\tau_j)w_i} + \frac{\tau_i E_i}{(1+\tau_i)w_i}\right] - \frac{\rho m_i}{Am}$$

or:

$$\frac{\frac{L}{N} + \frac{\rho m_i}{Am}}{\frac{m_i}{m}} = \left[\sum_{j=1}^{N} \frac{E_j}{(1+\tau_j)w_i} + \frac{\tau_i E_i}{(1+\tau_i)w_i}\right] \tag{A9}$$

From (A3) and (A9) we get:

$$\frac{\frac{L}{N} + \frac{\rho m_i}{Am}}{\frac{m_i}{m}} = \frac{\frac{L}{N} + \frac{\rho m_k}{Am}}{\frac{m_k}{m}}$$

or:

$$\frac{m_i}{m} = \frac{m_k}{m} = \frac{1}{N} \tag{A10}$$

Substituting (A10) into (A5) we get:

$$\frac{E_i}{w_i} = \left(L + \frac{\rho}{A}\right)\frac{(1+\tau_i)}{(N+\tau_i)} \qquad \text{(A11)}$$

Substituting equations (11) into (3), we obtain the amount of each good design j consumed by an agent:

$$y_{ij} = \frac{NE_i}{m(1+\mu_i)w_i} \qquad \text{(A12)}$$

The index of consumption or the real expenditure for each agent is obtained by substituting (A11) and (A12) into (2):

$$D_i(t) = m(t)^{\frac{1-\gamma}{\gamma}}\left(\frac{\rho}{A} + L\right)\frac{N(1+\tau_i)}{N+\tau_i}\frac{\gamma}{\gamma + b_i(1-\gamma)} \qquad \text{(A13)}$$

Substituting (A9) and (A10) into (A1) we get:

$$\rho + g = A\left[L + \frac{\rho}{A} - \sum_{j=1}^{N}\frac{E_j}{(1+\mu_j)w_j}\right] \qquad \text{(A14)}$$

Substituting (A11) into (A14), we get the innovation rate g:

$$g = AL - A\sum_{j=1}^{N}\frac{\gamma}{\gamma + b_i(1-\gamma)}\left(L + \frac{\rho}{A}\right)\frac{(1+\tau_i)}{(N+\tau_i)} \qquad \text{(A15)}$$

where g is positive iff:

$$\frac{AL}{(\rho + AL)} \geq \sum_{i=1}^{N}\frac{\gamma}{(\gamma + b_i(1-\gamma))}\frac{1+\tau_i}{N+\tau_i}$$

For the proof to be complete, we finally need to check that equilibrium wages are indeed such that the constraint of the producer's problem is binding. In the absence of constraint, producers of country i want to charge to consumers of country j a constant mark-up, $(1-\gamma)/\gamma$, over the marginal cost, inclusive of import tariffs. Therefore the price constraint will be binding iff:

$$\left(1+\frac{b_j(1-g)}{g}\right)w_j \leq \left(1+\frac{(1-g)}{g}\right)w_i(1+t_j) \quad \text{(A16)}$$

From (A9) and (A10), we have:

$$w_i = \frac{\left[\sum_{k=1}^{N}\frac{E_k}{(1+t_k)}\right]+\frac{t_i E_i}{(1+t_i)}}{L+\frac{r}{A}} \quad \text{(A17)}$$

Similarly,

$$w_j = \frac{\left[\sum_{k=1}^{N}\frac{E_k}{(1+t_k)}\right]+\frac{t_j E_j}{(1+t_j)}}{L+\frac{r}{A}} \quad \text{(A18)}$$

Using (A11), we can rewrite (A17) and (A18) as:

$$w_i = \frac{\left[\sum_{k=1}^{N}\frac{E_k}{(1+t_k)}\right]}{L+\frac{r}{A}}+\frac{t_i w_i}{N+t_i} \quad \text{(A19)}$$

$$w_j = \frac{\left[\sum_{k=1}^{N}\frac{E_k}{(1+t_k)}\right]}{L+\frac{r}{A}}+\frac{t_j w_j}{N+t_j} \quad \text{(A20)}$$

From (A19) and (A20) we obtain,

$$\frac{w_i}{w_j} = \frac{N+t_i}{N+t_j} \quad \text{(A21)}$$

Since $b_j \leq 1$, for (A16) to hold, we just need to check that:

$$1 \leq \frac{w_i(1+t_j)}{w_j} = \frac{N+t_i}{N+t_j}(1+t_j) \quad \text{(A22)}$$

The inequality (A22) hold for any non-negative (τ_i, τ_j) thus completing our proof.

Proof of Proposition 2

We divide the set of feasible policies $(\overline{\tau},\ \overline{b})$ into two regions: one region such that $g(\overline{\tau},\ \overline{b}) > 0$ and the other region such that $g(\overline{\tau},\ \overline{b}) = 0$. We first solve for optimal policies in the first region, then in the second region and finally compare welfare in both cases to conclude on the global optimum.

From (20), given no prohibitive tariffs, the joint maximization problem with international cooperation in both policy instruments for the case where the innovation rate is positive is:

$$\underset{t,b}{Max}\,U(t,b) = \frac{1}{r}\log\left[\frac{N}{\left(1+\frac{b(1-g)}{g}\right)}\left(L+\frac{r}{A}\right)\frac{(1+t)}{(N+t)}\right] + \frac{1-g}{g}\frac{\log m(0)}{r}$$
$$+\frac{1-g}{gr^2}\left[AL - \frac{AN}{\left(1+\frac{b(1-g)}{g}\right)}\left(L+\frac{r}{A}\right)\frac{(1+t)}{(N+t)}\right] \qquad \text{(A23)}$$

We assume that tariff is set first before patent breadth. Hence, taking derivative of (A23) w.r.t. b we have:

$$\frac{\partial U}{\partial b} = \frac{1}{\rho^2}\frac{1}{\left(\frac{\gamma}{1-\gamma}+b\right)}\left[-\rho+\frac{1}{\gamma}\frac{AL+\rho}{\left(1+\frac{b(1-\gamma)}{\gamma}\right)}\frac{N(1+\tau)}{(N+\tau)} - \frac{AL+\rho}{\left(1+\frac{b(1-\gamma)}{\gamma}\right)}\frac{N(1+\tau)}{(N+\tau)}\right]$$

(A24)

Since b≤1 and $\frac{N(1+\tau)}{(N+\tau)} \geq 1$,

$$\frac{\partial U}{\partial b} \geq \frac{1}{\rho^2}\frac{1}{\left(\frac{\gamma}{1-\gamma}+b\right)}\left[AL - \frac{AL+\rho}{\left(1+\frac{b(1-\gamma)}{\gamma}\right)}\frac{N(1+\tau)}{(N+\tau)}\right] \qquad \text{(A25)}$$

which, from (A15) implies:

$$\frac{\partial U}{\partial b} \geq \frac{1}{\rho^2}\frac{1}{\left(\frac{\gamma}{1-\gamma}+b\right)} g > 0 \qquad \text{(A26)}$$

Thus among the range of patent breadths such that the rate of innovation is positive, the optimal patent breadth is the maximum patent breadth b=1.

Substituting b=1 into (A23) and differentiating w.r.t. τ, we have:

$$\frac{\partial U}{\partial \tau} = \frac{1}{\rho^2}\frac{(N-1)}{(N+\tau)(1+\tau)}\left[\rho - (1-\gamma)(AL+\rho)\frac{N(1+\tau)}{(N+\tau)}\right] \qquad \text{(A27)}$$

Since $\frac{N(1+\tau)}{(N+\tau)} \geq 1$,

$$\frac{\partial U}{\partial \tau} \leq \frac{1}{\rho^2}\frac{(N-1)}{(N+\tau)(1+\tau)}\left[-AL + \gamma(AL+\rho)\frac{N(1+\tau)}{(N+\tau)}\right]$$

$$\Leftrightarrow \frac{\partial U}{\partial \tau} \leq -\frac{1}{\rho^2}\frac{(N-1)}{(N+\tau)(1+\tau)} g < 0$$

Since utility is strictly decreasing in tariff level, the optimal tariff is zero when innovation is positive. The welfare level when patent breadth is 1 and tariff is 0 is given by:

$$U(0,1) = \frac{1}{\rho}\log\left[\gamma\left(L+\frac{\rho}{A}\right)\right] + \frac{1-\gamma}{\gamma}\frac{\log m(0)}{\rho} + \frac{1-\gamma}{\gamma\rho^2}\left[AL - (AL+\rho)\gamma\right] \qquad \text{(A28)}$$

It is straightforward to show that U(0,1) is larger than welfare with prohibitive tariffs.

We next solve for optimal policies assuming that the rate of innovation is zero. In a symmetric equilibrium, the initial variety of goods produced by inventors in each country is the same, that is,

$$\frac{m_i(0)}{m(0)} = \frac{m_k(0)}{m(0)} = \frac{1}{N} \qquad \text{(A29)}$$

Since all labor is now allocated to manufacturing, the labor market clearing condition in each country is now given by:

$$\frac{L}{N} = m_i \sum_{j=1}^{N} \frac{E_j}{m(1+\mu)w_j} \qquad \text{(A30)}$$

At the symmetric equilibrium, expenditure and wages are the same across countries and hence we have:

$$E_i = \frac{1}{N} \qquad \text{(A31)}$$

$$w = \frac{1}{\left(1+\frac{1-\gamma}{\gamma}b\right)L} \qquad \text{(A32)}$$

The amount of each variety consumed by the representative agent is obtained by substituting (A31) and (A32) into (A12):

$$y_{ij} = \frac{L}{m(0)} \qquad \text{(A33)}$$

Substituting (A33) into (1), we find that welfare is the same for all $(\overline{\tau}, \overline{b})$ such that $g(\overline{\tau}, \overline{b}) = 0$ and is given by:

$$U = \frac{1}{\rho}\log L + \frac{1-\gamma}{\gamma}\frac{\log m(0)}{\rho} \qquad \text{(A34)}$$

We need to compare (A34) to (A28) to find out whether a positive innovation rate is optimal.

$$\begin{aligned} U(0,1) - U(\tau,b)\big|_{g=0} &= \frac{1}{\rho}\ln\left[\gamma\left(L+\frac{\rho}{A}\right)\right] - \ln L + \frac{1-\gamma}{\gamma\rho^2}\left[AL - (AL+\rho)\gamma\right] \\ &= \frac{1}{\rho}\left\{\ln\left[\gamma(AL+\rho)\right] - \ln AL + \frac{1-\gamma}{\gamma\rho}\left[AL - (AL+\rho)\gamma\right]\right\} \end{aligned} \qquad \text{(A35)}$$

The term in curly bracket is positive iff:

$$\ln \text{AL} - \ln[\gamma(\text{AL}+\rho)] < \frac{1-\gamma}{\gamma\rho}[\text{AL}-(\text{AL}+\rho)\gamma] \tag{A36}$$

From Assumption 3, we note that:

$$\frac{1-\gamma}{\gamma\rho}[\text{AL}-(\text{AL}+\rho)\gamma] < \frac{1}{(\text{AL}+\rho)\gamma}[\text{AL}-(\text{AL}+\rho)\gamma] \tag{A37}$$

Therefore, welfare with positive innovation is strictly larger than welfare with zero innovation since, by the mean value theorem, it is true that:

$$\frac{\ln \text{AL} - \ln[\gamma(\text{AL}+\rho)]}{\text{AL}-(\text{AL}+\rho)\gamma} < \frac{1}{(\text{AL}+\rho)\gamma} \tag{A38}$$

Optimal patent breadth and optimal tariff when countries engage in binding agreements in both tariffs and patent protection is therefore given by 1 and 0, respectively.

<u>Proof of Proposition 3</u>

Assuming that the innovation rate is positive, each country solves the following maximization problem:

$$\begin{aligned} \underset{t_i,b_i}{Max}\, U(\bar{t},\bar{b}) = \frac{1}{r}\log\frac{gN}{g+b_i(1-g)}(L+\frac{r}{A})\frac{1+t_i}{N+t_i} + \frac{(1-g)}{g}\frac{\log m(0)}{r} \\ + \frac{(1-g)}{gr^2}\left[AL - A\sum_{j=1}^{N}\frac{g}{g+b_j(1-g)}(L+\frac{r}{A})\frac{1+t_j}{N+t_j}\right] \end{aligned} \tag{A39}$$

We solve for the case where tariff is set first before patent protection. Solving by backward induction we first differentiate (A39) w.r.t. b_i:

$$\frac{\partial U}{\partial b_i} = -\frac{1}{r}\frac{1-g}{(g+b_i(1-g))} + \frac{1-g}{gr^2}\left[\frac{A}{\frac{g}{1-g}\left(1+\frac{b_i(1-g)}{g}\right)^2}\left(L+\frac{r}{A}\right)\frac{(1+t_i)}{(N+t_i)}\right] \tag{A40}$$

(A40) implies that the optimal patent breadth as a function of tariff is given by:[14]

$$b_i^u = \begin{cases} \left[\dfrac{(\rho + AL)}{\rho}\dfrac{1+\tau_i}{N+\tau_i} - \dfrac{\gamma}{1-\gamma}\right] & \text{if } \tau_i \le \dfrac{N\rho - (1-\gamma)(\rho + AL)}{(1-\gamma)(\rho + AL) - \rho} \\ 1 & \text{if } \tau_i > \dfrac{N\rho - (1-\gamma)(\rho + AL)}{(1-\gamma)(\rho + AL) - \rho} \end{cases} \quad \text{(A41)}$$

$$\text{Let } T \equiv \frac{N\rho - (1-\gamma)(\rho + AL)}{(1-\gamma)(\rho + AL) - \rho} \quad \text{(A42)}$$

If $\tau_i \le T$, at the symmetric Nash equilibrium, all countries implement the same optimal patent breadth given by (A41). Substituting (A41) into (A15) we obtain the innovation rate:

$$g = AL - \frac{N\gamma\rho}{1-\gamma} \quad \text{(A43)}$$

Substituting (A41) and (A43) into the representative agent's utility function we get:

$$U = \frac{1-\gamma}{\gamma}\frac{\log m(0)}{\rho} - \frac{1}{\rho}\log\frac{A(1-\gamma)}{N\gamma\rho} + \frac{1-\gamma}{\gamma\rho^2}\left[AL - \frac{N\gamma\rho}{1-\gamma}\right] \quad \text{(A44)}$$

The representative agent's utility is thus independent of tariff.

If $\tau_i > T$, then optimal patent breadth is 1 and the representative agent's utility is given by:

$$U = \frac{1-\gamma}{\gamma}\frac{\log m(0)}{\rho} + \frac{1}{\rho}\log\left(\frac{\rho}{A} + L\right)\frac{1+\tau_i}{N+\tau_i} - \log\frac{1}{\gamma} + \frac{1-\gamma}{\gamma\rho^2}\left[AL - \gamma\sum_{i=1}^{N}(\rho + AL)\frac{1+\tau_i}{N+\tau_i}\right]$$

$$\left.\frac{dU}{d\tau_i}\right|_{\tau_i > T} = \frac{1}{\rho}\frac{N-1}{(1+\tau_i)(N+\tau_i)} - \frac{1-\gamma}{\rho^2}\frac{N-1}{(N+\tau_i)^2}(\rho + AL) \quad \text{(A45)}$$

$$\left.\frac{dU}{d\tau_i}\right|_{\tau_i > T} = \frac{1}{\rho}\frac{N-1}{(1+\tau_i)(N+\tau_i)}\left[1 - \frac{1-\gamma}{\rho}\frac{(1+\tau_i)}{(N+\tau_i)}(\rho + AL)\right] < 0 \quad \text{(A46)}$$

Therefore, it is not optimal to raise tariff beyond T.

[14] One can easily check that the second order condition holds.

To conclude, optimal tariffs and patent breadths are indeterminate in the case where positive innovation is optimal but they satisfy the following conditions:

$$\tau^u \le \frac{N\rho-(1-\gamma)(\rho+AL)}{(1-\gamma)(\rho+AL)-\rho} \text{ and}$$

$$\frac{(\rho+AL)}{\rho}-\frac{\gamma}{1-\gamma}-\frac{(\rho+AL)}{\rho}\frac{N-1}{N+\tau^u}-b^u=0$$

Proof of Proposition 4

Substituting the common level of patent breadth b* enforced by all countries into (20) and taking the derivative w.r.t. τ_i:

$$\frac{dU}{d\tau_i}=\frac{1}{\rho}\frac{N-1}{(1+\tau_i)(N+\tau_i)}-\frac{1-\gamma}{\rho^2}\frac{1}{\gamma+b*(1-\gamma)}\frac{N-1}{(N+\tau_i)^2}(\rho+AL) \tag{A47}$$

$$\Leftrightarrow \frac{dU}{d\tau_i}=\frac{1}{\rho}\frac{N-1}{(1+\tau_i)(N+\tau_i)}\left[1-\frac{1-\gamma}{\rho}\frac{1}{\gamma+b*(1-\gamma)}\frac{(1+\tau_i)}{(N+\tau_i)}(\rho+AL)\right] \tag{A48}$$

Let B be the patent breadth such that:

$$\left[1-\frac{1-\gamma}{\rho}\frac{1}{\gamma+B(1-\gamma)}\frac{1}{N}(\rho+AL)\right]=0 \tag{A49}$$

$$\text{Then, } B=\frac{(\rho+AL)}{N\rho}-\frac{\gamma}{1-\gamma} \tag{A50}$$

For b*<B, $\frac{dU}{d\tau_i}<0$. Hence, optimal tariff is 0.

Substituting zero tariff into the representative agent's utility function:

$$U(\overline{0},\overline{b}*)=\frac{1-\gamma}{\gamma}\frac{\log m(0)}{\rho}+\frac{1}{\rho}\log\left(\frac{\rho}{A}+L\right)+\frac{1}{\rho}\log\frac{\gamma}{\gamma+b*(1-\gamma)} + \frac{1-\gamma}{\gamma\rho^2}\left[AL-\frac{\gamma(\rho+AL)}{\gamma+b*(1-\gamma)}\right] \tag{A51}$$

$$\frac{\partial U}{\partial b*}=\frac{1-\gamma}{[\gamma+b*(1-\gamma)]\rho^2}\left[-\rho+\frac{(1-\gamma)(AL+\rho)}{[\gamma+b*(1-\gamma)]}\right] \tag{A52}$$

For b*<B, $\frac{\partial U}{\partial b^*} > 0$, hence it is never optimal to set patent breadth strictly below B.

For $b^* \in [B, 1]$, the optimal tariff of each individual country is given by:

$$\hat{\tau}_i = \frac{N - \frac{1-\gamma}{\rho}\frac{(\rho + AL)}{\gamma + (1-\gamma)b^*}}{\frac{1-\gamma}{\rho}\frac{(\rho + AL)}{\gamma + (1-\gamma)b^*} - 1} \tag{A53}$$

It can easily be checked that the optimal tariff is strictly less than the prohibitive tariff. Substituting the Nash equilibrium optimal tariff into the representative agent's utility, we get:

$$U = \frac{1-\gamma}{\gamma}\frac{\log m(0)}{\rho} - \frac{1}{\rho}\log\frac{A(1-\gamma)}{N\gamma\rho} + \frac{1-\gamma}{\gamma\rho^2}\left[AL - \frac{N\gamma\rho}{1-\gamma}\right] \tag{A54}$$

Since b* does not enter (A54), any $b^* \in \left[\frac{(\rho + AL)}{N\rho} - \frac{\gamma}{1-\gamma}, 1\right]$ is optimal.

Furthermore, comparing (A54) with (A44), we observe that the welfare is the same as the non-cooperative equilibrium.

Proof of Proposition 5

Taking the common level of tariff agreed by all countries τ^* as given, we first find the optimal patent breadth chosen by individual countries. From the proof of Proposition 3, we obtain the optimal patent breadth as:

$$\hat{b}_i = \begin{cases} \left[\frac{(\rho + AL)}{\rho}\frac{1+\tau^*}{N+\tau^*} - \frac{\gamma}{1-\gamma}\right] & \text{if} \quad \tau^* \in \left[0, \frac{N\rho - (1-\gamma)(\rho + AL)}{(1-\gamma)(\rho + AL) - \rho}\right] \\ 1 & \text{if} \quad \tau^* > T = \frac{N\rho - (1-\gamma)(\rho + AL)}{(1-\gamma)(\rho + AL) - \rho} \end{cases} \tag{A55}$$

If every country implements maximum patent breadth (b=1), we know from the proof of Proposition 3 that utility is decreasing in the common level of tariff adopted.

Therefore it is never optimal for countries to agree on a tariff level higher than T.

For tariff levels $\tau^*<T$, optimal patent breadth is given by (A55) and hence the representative agent's utility is given by:

$$U = \frac{1-\gamma}{\gamma}\frac{\log m(0)}{\rho} - \frac{1}{\rho}\log\frac{A(1-\gamma)}{N\gamma\rho} + \frac{1-\gamma}{\gamma\rho^2}\left[AL - \frac{N\gamma\rho}{1-\gamma}\right] \qquad \text{(A56)}$$

Hence utility is independent of tariff and the same as the non-cooperative equilibrium.

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