Is there a case for non-discrimination in the international protection of intellectual property?*

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Abstract

We evaluate the case for non-discrimination in international patent protection. When trade is not subject to any frictions or barriers, requiring national treatment (NT) in patent protection does not affect the rate of innovation (and welfare) since unfavorable discrimination suffered abroad by innovators is fully offset by favorable discrimination enjoyed by them at home. When trade barriers exist, however, such international offsetting in patent protection is incomplete and innovation incentives are actually lower under NT. By lumping domestic and foreign patent protection together, NT blunts the overall effectiveness of patent protection in incentivizing innovation in the presence of trade barriers.

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1 Introduction

The Agreement on the Trade Related Aspects of Intellectual Property (TRIPS) was easily the most controversial outcome of the Uruguay Round of multilateral trade negotiations (1986-95). Due to this far-reaching agreement, all WTO members – regardless of their economic status and/or innovative capabilities – are obligated to adopt certain minimum standards of protection for all major types of intellectual property such as copyrights, patents, and trademarks.[1] For example, TRIPS mandates that the duration of patent protection granted by WTO members must be at least 20 years. In addition to such harmonization, an equally important aspect of TRIPS is that it requires intellectual property policies of WTO members to abide by certain fundamental principles, such as *non-discrimination*.[2] The non-discrimination requirement in TRIPS manifests itself in two forms: the principle of national treatment (NT) that forbids discrimination between domestic and foreign firms/nationals with regard to the protection of intellectual property and the most favored nation (MFN) clause that prohibits discrimination between foreign nationals originating from different countries.[3]

Our primary objective in this paper is to evaluate the case for NT in the protection of intellectual property. At first glance, the inclusion of NT in TRIPS seems hardly worthy of discussion; after all, NT is a central principle of all other multilateral agreements of the WTO. So why should TRIPS be any different? Nevertheless, we show in this paper that the desirable properties of NT in the context of trade in goods and services do not automatically carry over to the domain of intellectual property. To investigate the economic effects of requiring countries to follow NT in the protection of intellectual property, we utilize an adapted version of the Grossman and Lai (2004) model of international patent protection and innovation.[4] Our conceptual approach is straightforward

[1] See Maskus (2000) for a comprehensive discussion of the economics of intellectual property rights protection in the global economy and the international externalities that a multilateral agreement such as TRIPS attempts to internalize.

[2] To be sure, the principle of non-discrimination predates TRIPS but historical international intellectual property treaties (such as the Paris and Berne Conventions) were not backed by a powerful dispute settlement procedure like the one that is available to WTO members today.

[3] The NT requirement is specified in Article 3 of TRIPS which says that "Each Member shall accord to the nationals of other Members treatment no less favorable than that it accords to its own nationals with regard to the protection of intellectual property." MFN is contained in Article 4 which says that "any advantage, favour, privilege or immunity granted by a Member to the nationals of any other country shall be accorded immediately and unconditionally to the nationals of all other Members." These twin principles of non-discrimination are found in some shape or form in every multilateral trade agreement of the WTO.

[4] Their work builds on Nordhaus (1969) who first addressed the question of optimal patent policy in a closed economy.

and informative: we simply compare equilibrium outcomes and welfare in the absence of NT with those obtained in its presence. While our model focuses on patent policy, the insights it yields should also be relevant for other instruments of intellectual property protection such as copyrights and trademarks.

In accordance with Article 3 of TRIPS, Grossman and Lai (2004) focus on non-discriminatory patent policies and show two major results. First, countries tend to offer too little patent protection in an open economy setting. Second, the harmonization of patent protection across countries is neither necessary nor sufficient for achieving efficiency since it does not address the underlying problem of under-protection. In the present paper, we build on their insights by examining the implications of the non-discrimination constraint on national patent policies imposed by NT thereby adding to our understanding of the economic consequences of TRIPS.[5]

Issues surrounding the international protection of intellectual property have often been examined in the literature through the lens of North-South models of international trade and endogenous innovation.[6] While these models provide important insights, they do not derive optimal patent policies: instead they either consider the effects of marginal changes in an exogenously given rate of Southern imitation or examine policies that, on the margin, lower incentives for (endogenous) imitation. Thus, by design, they do not address the implications of core TRIPS principles such as NT for equilibrium patent policies and welfare.

While little is known about how NT operates in the context of intellectual property, the effects of non-discrimination in the use of domestic tax instruments such as sales taxes are fairly well-understood in the literature. Horn (2006) makes the important point that while NT with respect to internal taxes and other such domestic instruments can prevent countries from pursuing legitimate objectives, trade agreements that do not contain such a clause can be easily subverted by national governments who have an incentive to favor domestic firms over foreign ones. Thus, according to this view, NT serves as a line of defense against beggar-thy-neighbor tendencies of individual nations.[7]

[5] In Grossman and Lai (2004) as well as in our model, all innovation is conducted by the private sector. See Scotchmer (2004) for an analysis of intellectual property treaties in a model where R&D is conducted by both the private and the public sector.

[6] Much of this literature follows Grossman and Helpman (1991) who provide a comprehensive and unified treatment of the two leading approaches – i.e. the variety expansion model and the quality ladders model. Further building on this work, Helpman (1993) analyzes how a decline in Southern imitation affects global welfare both in the steady state and during the transition path.

[7] Saggi and Sara (2008) take Horn's analysis further by studying the role of NT when countries are heterogeneous in market size and/or the quality of goods produced and the mutual agreement over NT is endogenously determined. Horn, Maggi, and Staiger (2010) examine the role of NT from the

Horn's (2006) basic query is no less relevant in the realm of intellectual property: when and why does it make sense to constrain national policies in the manner specified by NT? To be sure, incentives to pursue beggar-thy-neighbor policies are pervasive in the context of intellectual property.[8] After all, a major reason the US and, to a lesser extent, the EU pushed hard for a multilateral agreement on intellectual property during the Uruguay round negotiations was that major developing economies such as Brazil, China, and India were offering little or no intellectual property protection to their firms, a policy environment that fostered widespread imitation and reverse-engineering of Western technologies by local firms in such countries. But does the presence of such beggar-thy-neighbor incentives necessarily generate a rationale for non-discrimination in the protection of intellectual property? Our analysis below shows that it *does not*.

Our baseline model considers a world of two countries and analyzes the effects of NT when trade between them is not subject to any frictions or barriers. Somewhat expectedly, we find that in the absence of a NT requirement, each country finds it optimal to grant weaker protection to foreign firms relative to domestic ones. This discrimination arises because governments do not care about the effects of their policies on the profits earned by foreign firms. However, we show that discrimination against foreign firms on the part of both countries does *not* have any welfare consequences. To understand the intuition for this surprising result, first note that a firm's incentive for innovation depends upon the level of *effective global protection* available to it under alternative policy regimes, where the level of effective global protection is defined as a weighted sum of the patent protection granted by each country, with a country's weight being equal to its market size. The reason NT fails to generate any welfare improvement under free trade in our model is that what each firm gains in terms of higher patent protection abroad if discrimination is replaced by NT is exactly offset by what it loses at home so that the effective global protection facing firms remains unchanged.

In section 4, we show that this invariance of innovation incentives and welfare to NT does not obtain in the presence of trade frictions. When international trade is subject to frictions – such as transportation and/or communication costs – *NT lowers innovation incentives by reducing the effective global protection enjoyed by firms.* The intuition for this result is as follows. While trade frictions lower export profits and make foreign patent protection relatively less important for incentivizing innovation in each country,

perspective of incomplete contracts.

[8]Lerner (2002) notes that prior to the emergence of major international agreements on intellectual property, discrimination against foreign patent applications was quite common during the mid 19th century across the world. Discriminatory measures used against foreigners included shorter duration of patents, higher fees, shorter extensions, and premature patent expirations. See also Goldstein (2001).

NT actually calls for each country to provide more of such protection rather than less. From the viewpoint of firms, in the presence of trade frictions favorable discrimination granted at home in the absence of NT more than offsets the negative incentive effects of unfavorable discrimination suffered abroad. Consumer welfare considerations reinforce the argument in favor of discrimination: due to trade frictions, the consumer surplus obtained by each country from foreign innovations is smaller than that obtained from domestic ones.[9] Indeed, we show that for any positive level of trade frictions, it is actually *jointly optimal* to have each country offer a lower level of patent protection to foreign firms relative to domestic ones, a policy configuration precluded by NT.

We also find that a reduction in trade frictions reduces each country's incentive to discriminate against foreigners since domestic consumers derive greater benefits from foreign innovations when trade is freer. This result points to a potential synergy between the acceptance of international disciplines on intellectual property and the degree of trade liberalization in the global economy. It is worth noting here that TRIPS agreement followed almost five decades of multilateral trade liberalization achieved over eight separate rounds of trade negotiations conducted under the auspices of the General Agreement on Tariffs and Trade (GATT). As is well known, pre-TRIPS rounds of GATT negotiations were successful in lowering the average global tariff on industrial goods from over 40% to under 4% (Bagwell and Staiger, 2002). Our analysis suggests that such multilateral trade liberalization during GATT years may have helped pave the way for TRIPS by making international disciplines on intellectual property more palatable to countries.

Our analysis also shows that differences in market size across countries affects incentives for discrimination in somewhat surprising ways. An important result in this regard is that if the market size of a country increases relative to the other, its incentive to discriminate against foreign firms *declines* while its level of patent protection increases. Intuitively, as a country's market size increases, its weight in determining the level of effective global protection increases as does the benefit it enjoys from foreign innovations. Indeed, if one country becomes arbitrarily large relative to the other, its incentives for patent protection essentially converge to those of a closed economy since foreign consumers become a negligible part of the calculus determining optimal patent policies.

Our result that a larger market has a weaker incentive to discriminate against foreign nationals seems to accord quite well with the fact that, during the Uruguay round, mul-

[9] The empirical link between the protection of intellectual property and the volume and pattern of international trade was first established by Maskus and Penubarti (2001). See Maskus and Yang (2013) for a more recent investigation of related issues.

tilateral disciplines on intellectual property were pushed strongly by the two largest economies in the world (i.e. the US and the EU). From the perspective of these economies, TRIPS was primarily a means for getting developing countries to accept disciplines such as NT and MFN along with an increase in the degree of intellectual property protection that they had to extend to innovators. Furthermore, the model also clarifies that small developing countries not only have a weaker incentive to protect intellectual property because their own markets are too small to affect global innovation, they also lose more from having to follow the non-discrimination principle of NT. In this regard, it is noteworthy that in accordance with the general principle of special and differential treatment at the WTO, when TRIPS was ratified in 1995, developing countries were given an additional five years to achieve TRIPS compliance while the least-developed countries had until 2006 to do so, which was then further extended to 2013 in general, and to 2016 for the enforcement of pharmaceutical patents and laws applying to trade secrets.

Since an increase in market size asymmetry reduces the degree of discrimination in the larger market while it raises it in the smaller market, the average degree of discrimination declines in our model as markets become more unequal in size. For analogous reasons, the degree of effective global protection increases with market size asymmetry. Both of these factors imply that the global welfare loss generated by NT declines as markets become more asymmetric in size. This aspect of our model contrasts sharply with analyses of international trade agreements over conventional policy instruments such as tariffs and internal taxes since coordination over these traditional instruments as well as non-discrimination requirements with respect to their use generally become harder to implement as countries become less similar to each other – see, for example, Park (2000), Horn (2006), and Sara and Saggi (2008). In such models, as a country gets larger (i.e. has more market power) it tends to typically increase its tariff or tax but such a change immiserizes the other country. By contrast, in the present context, as the larger country increases its patent protection and lowers its discrimination against foreign firms, the smaller country's welfare increases as does its ability to *lower* its own protection since innovation incentives of firms depend only on the effective global protection that they receive, and not on its composition across countries. Thus, the type of international spillovers that an international agreement over intellectual property helps internalize are fundamentally different in character from those internalized by trade agreements over tariffs and other trade policies.[10] However, the different nature of spillovers in the context

[10] Bagwell and Staiger (1999 and 2002) argue that the GATT/WTO principles of MFN and reciprocity help achieve efficiency when international trade agreements are motivated by the presence of terms of

of patent protection is not the key driving force behind our surprising findings. Positive international spillovers created by patent protection only imply that there exists global under-protection of patents. The key reason discriminatory patent policies dominate NT in the presence of trade frictions is that such frictions make each country's innovation relatively less responsive to foreign patent protection and by forcing each country to offer the same level of protection to domestic and foreign firms, *NT reduces the overall effectiveness of patent protection as an instrument for encouraging innovation.*

Our paper echoes an emerging empirical literature that examines how effectively countries practice non-discriminatory IPR policies during the post-TRIPS era. Rather surprisingly, existing evidence suggests that even WTO members tend to discriminate against foreign innovators in practice. For example, Webster et. al. (2014) find that, all else equal, both European and Japanese patent offices are more likely to grant patents to domestic applicants relative to foreign ones. In similar vein, using data for Canada, Mai and Stoyanov (2014) find that Canadian firms are substantially more likely to win court cases when the dispute involves foreign firms as opposed to other Canadian firms. Consistent with these empirical findings, our paper shows that countries indeed have incentives to use discriminatory patent policies in the absence of NT. More importantly, our paper establishes that the use of such discriminatory patent policies can be welfare-enhancing relative to NT when international trade is subject to frictions.[11]

2 Baseline model

To study NT in the international protection of intellectual property, we utilize the two-sector model of ongoing innovation developed by Grossman and Lai (2004). Before describing policy choices, we summarize the underlying economic environment. The world consists of two countries: Home (H) and Foreign (F). In each country, a traditional sector produces a homogeneous good (which serves as the numeraire) while a modern sector produces a variety of differentiated goods. The representative consumer maximizes her lifetime utility

$$U(t) = \int_t^\infty e^{-\rho z} u(z) dz \tag{1}$$

trade externalities between countries.

[11] Lai (2007) also examines incentives for discriminatory patent policies in the absence of NT. However, he only considers a world of free trade and does not analyze how innovation and welfare differ across the two types of patent regimes (i.e. discrimination and NT).

where ρ is the subjective discount rate and $u(\cdot)$ is the instantaneous utility function given by

$$u(z) = y(z) + \int_0^{n(z)} h(x(i,z))di \tag{2}$$

where $y(z)$ and $x(i,z)$ represent respectively the consumptions of the homogeneous good and the ith differentiated good at time z and $n(z)$ denotes the measure of differentiated goods that are still alive at time z. As in Grossman and Lai (2004), the function $h(.)$ is assumed to satisfy the following regularity conditions (i) $h' > 0$ and $h'' < 0$; (ii) every variety of differentiated goods is purchased in equilibrium (i.e. $h'(0) = \infty$); and (iii) optimal monopoly price of a typical differentiated good is finite (i.e. $-xh''/h' < 1$).

Given the preferences in (1) and (2), the representative consumer first chooses the consumption of differentiated goods and then purchases the homogeneous good with the remainder of her income (which is assumed to be positive). There are M_i consumers in country i, where $i = H, F$, so that M_i measures country i's market size for differentiated goods.

There are two factors of production: capital (K) and labor (L). The amount of labor needed to produce one unit of the numeraire or that of a typical differentiated good in country i equals a_i. The total labor resource in country i, L_i, is assumed to be sufficiently large so that a positive amount of the numeraire good is produced in equilibrium in each country. Since the market for the numeraire good is assumed to be perfectly competitive, the wage rate in country i simply equals the marginal product of labor in the traditional sector: i.e. $w_i = 1/a_i$.

Prior to being produced, a differentiated good must be first invented by R&D which requires a combination of labor (L) and human capital (K). For simplicity, the research technology in country i is assumed to take the Cobb-Douglas form:

$$\phi_i(z) = A[L_{Ii}(z)/a_i]^{\alpha}(K_i)^{1-\alpha} \tag{3}$$

where $\phi_i(z)$ is the flow of innovations at time z, $A > 0$ is a constant, $L_{Ii}(z)$ is the labor allocated to innovation, a_i represents labor productivity, and K_i represents the fixed stock of human capital.[12]

[12] Our major results continue to hold when the production function for research has a CES form of the type $\phi_i(z) = A[\alpha[L_{Ii}(z)/a_i]^{\beta} + (1-\alpha)K_i^{\beta}]^{1/\beta}$ with $\beta \leq 0$. As is well-known, the Cobb-Douglas production function obtains when $\beta = 0$. In the more general CES case, the assumption that $\beta \leq 0$ has two implications. First, the responsiveness of innovation to patent protection decreases as the latter rises. Second, patent protection policies of different countries are strategic substitutes for one another. We consider both these features to be quite realistic.

A differentiated good has a finite life span ($\overline{\tau}$) during which it generates positive utility for consumers. At the end of its life span, a differentiated good produces zero utility for consumers and is therefore no longer produced. Given the technology specified for innovation in (3), during each time period z, $\phi_i(z)+\phi_j(z)$ newly invented goods enter country i's market while a measure of $\phi_i(z-\overline{\tau})+\phi_j(z-\overline{\tau})$ existing goods die and exit the market. As a result, the growth in the measure of differentiated good at a given point in time is $\dot{n}_i(z)=\phi_i(z)-\phi_i(z-\overline{\tau})+\phi_j(z)-\phi_j(z-\overline{\tau})$. We focus on the steady state of the world economy where the measure of differentiated good in both markets remains constant over time, i.e. $\dot{n}_i(z)=0$.

After it has been invented, a differentiated good can be targeted by imitators. To protect differentiated goods from imitation, the government in each country grants patent rights to inventing firms. While the patent is in effect, the patenting firm charges its optimal monopoly price. Let π be the instantaneous per capita profit of a monopolist producing a patented differentiated good so that $\pi=(p_m-aw)x_m$. Let the index of patent protection be defined as

$$\Omega=(1-e^{-\rho\tau})/\rho \tag{4}$$

where ρ is the rate of time preference.[13] By design, the present value of expected per capita profits from patenting a newly invented good equals $\Omega\pi$. After the expiration of its patent, a differentiated good can be imitated free of cost. Imitation drives the price of the good to its competitive level so that the post-imitation profits of an innovator equal zero.

When analyzing optimal patent protection, Grossman and Lai (2004) focus on policies that abide by the non-discrimination principle of NT. As we noted earlier, Article 3 of TRIPS indeed requires countries to extend the same patent protection to all firms regardless of their national origin. One of our key objectives, however, is to examine the implications of the *constraint* that NT places on the patent policies of individual nations. To do so, we allow countries to *discriminate* between domestic and foreign firms by formulating and implementing patent protection policies that depend upon the national origin of firms. Accordingly, let country i extend patent protection Ω_{ii}^R to domestic firms and Ω_{ij}^R to foreign ones under regime R, where $R=D$ (discrimination) or NT and $\Omega_{ii}=\Omega_{ij}$ under NT.

Under regime R, a firm from country i that is successful in innovation earns total profit $\pi M_i\Omega_{ii}^R$ in the home market and $\pi M_j\Omega_{ji}^R$ overseas. The value of a typical innovating

[13] In Grossman and Lai (2004) a patent is assumed to have two dimensions: length τ and the degree of enforcement ω where $\omega\in[0,1]$. But since ω plays no role in our analysis that is separate from patent length, we normalize ω to 1.

firm from country i therefore equals $v_i^R = (M_i\Omega_{ii}^R + M_j\Omega_{ji}^R)\pi$. Firms make decisions about their labor inputs for R&D based on their expected total profits in the global market. The first-order condition determining demand for labor in country i under regime R where $R = D$ or NT is

$$v_i^R \frac{\partial F_i(L_{Ii}, K_i)}{\partial L_{Ii}} = w_i.$$

Let C_m and C_c be the instantaneous (per capita) consumer surplus levels under monopoly and competition respectively, i.e. $C_m = h(x_m) - p_m x_m$ and $C_c = h(x_c) - p_c x_c$. Let $\overline{T} = (1 - e^{-\rho\overline{\tau}})/\rho$ be the present value of a 1 dollar flow over the entire useful life of a typical patented product. Then, the present value of surplus enjoyed by a typical consumer in country i over the entire life of a domestic differentiated product can be written as

$$C_m\Omega_{ii}^R + C_c(\overline{T} - \Omega_{ii}^R)$$

and that derived from a foreign differentiated good as

$$C_m\Omega_{ij}^R + C_c(\overline{T} - \Omega_{ij}^R)$$

Let Λ_0 denote the welfare derived from goods invented prior to the implementation of the patent policy. We may then write country i's national welfare under regime R where $R = D$ or NT, as

$$\begin{aligned} W_i^R &= \Lambda_{i0} + \frac{w_i}{\rho}(L_i - L_{Ii}^R) + \frac{M_i\phi_i^R}{\rho}[C_m\Omega_{ii}^R + C_c(\overline{T} - \Omega_{ii}^R)] \\ &\quad + \frac{M_i\phi_j^R}{\rho}[C_m\Omega_{ij}^R + C_c(\overline{T} - \Omega_{ij}^R)] + \frac{\pi\phi_i^R}{\rho}(M_i\Omega_{ii}^R + M_j\Omega_{ji}^R). \end{aligned} \tag{5}$$

Similarly, let aggregate world welfare be defined simply as the sum of national welfare of each country:

$$WW^R = \sum_i W_i^R. \tag{6}$$

We proceed by deriving equilibrium policies under discrimination and then impose the NT constraint on each country to see how it affects equilibrium policies and welfare. It is obvious that, in our model, the unilateral imposition of NT on a country can only make it worse off since even in the absence of NT it can always choose not to discriminate if it is welfare-maximizing to do so. But the more subtle issue, and the one that we address below, is how the simultaneous adoption of NT by both countries affects market outcomes and welfare.

3 Effects of NT in the absence of trade frictions

We begin with the scenario where international trade is not subject to any frictions or barriers. An important implication of this assumption is that from a social welfare perspective, patent protection abroad is just as valuable to firms as patent protection in their domestic markets. In section 4, we will show that the introduction of trade frictions breaks this equivalence which, in turn, has implications for equilibrium policies and welfare under the two types of patent regimes.

3.1 Discriminatory patent protection

In what follows, we derive the non-cooperative Nash equilibrium where each country simultaneously and independently determines its domestic and foreign patent protections, treating these protections in the other country as given. The objective of each government is to maximize national welfare. In particular, we assume *interior* solutions for both the NT and discrimination regimes, meaning that patent protections implemented by governments lie strictly between 0 and $\overline{T}$.

Let us first consider the case where countries are free to implement discriminatory patent policies. Following Grossman and Lai (2004), it turns out to be more intuitive to derive the best response curves of countries by equating each country's marginal benefit of patent protection to the associated marginal cost, taking the policies of the other country as given.

Consider the patent policies of country i. A marginal increase in its domestic protection Ω_{ii} raises the value of all domestic innovators by extending their monopoly tenures. This leads to more R&D investment and a greater variety of differentiated goods invented by such firms. Each new differentiated good generates a discounted per-consumer surplus of $\frac{1}{\rho}[C_m\Omega_{ii} + C_c(\overline{T} - \Omega_{ii})]$ over its lifetime. It follows that country i's marginal benefit of domestic protection Ω_{ii} is

$$\frac{M_i}{\rho}\frac{\partial \phi_i^D}{\partial \Omega_{ii}}[C_m\Omega_{ii} + C_c(\overline{T} - \Omega_{ii})] \tag{7}$$

where $\frac{\partial \phi_i^D}{\partial \Omega_{ii}}$ represents the response of local innovation to a small change in domestic patent protection.

In the appendix, we show that

$$\frac{\partial \phi_i^D}{\partial \Omega_{ii}} = \frac{\gamma \phi_i^D M_i}{M_i\Omega_{ii} + M_j\Omega_{ji}}$$

where $\gamma = \frac{\alpha}{1-\alpha}$ represents the responsiveness of innovation to the value of an innovation in elasticity form. Plugging this expression into (7), one obtains the following expression for country i's marginal benefit of raising domestic protection

$$\frac{1}{\rho}\frac{\gamma\phi_i^D M_i^2}{M_i\Omega_{ii} + M_j\Omega_{ji}}[(C_m - C_c)\Omega_{ii} + C_c\overline{T}]. \tag{8}$$

On the other hand, a marginal increase in domestic patent protection allows all existing innovators to charge monopoly prices for a longer time period. This causes a loss of consumer surplus, which is partially offset by the greater monopoly profits accruing to domestic innovators. Since ϕ_i^D new goods are invented per unit of time, country i's discounted marginal cost of domestic patent protection Ω_{ii} equals

$$\frac{M_i\phi_i^D(C_c - C_m - \pi)}{\rho}. \tag{9}$$

Equating the marginal benefit (8) of domestic patent protection Ω_{ii} to its marginal cost (9) and rearranging terms gives the first order condition determining Ω_{ii}:[14]

$$C_c - C_m - \pi = \frac{\gamma M_i}{M_i\Omega_{ii} + M_j\Omega_{ji}}[(C_m - C_c)\Omega_{ii} + C_c\overline{T}]. \tag{10}$$

Equation (10) describes country i's best response Ω_{ii} to the degree of patent protection that country j extends to country i (Ω_{ji}). It is easy to see from (10) that since $C_m < C_c$, Ω_{ii} is a decreasing function of Ω_{ji}: country i finds it optimal to lower the patent protection that it grants to local innovating firms if they receive more protection from country j. The intuition behind this is straightforward. An increase in Ω_{ji} increases the value of innovation made by country i's firms and thereby encourages them to invest more in R&D. However, due to diminishing returns in R&D, country i's marginal benefit of extending patent protection to its own firms is lower when Ω_{ji} is larger. As a result, Ω_{ii} has to fall in order to bring the marginal benefit back to the level of the marginal cost, namely, $C_c - C_m - \pi$. This implies that Ω_{ii} and Ω_{ji} are *substitutable* patent policies.

Observe from (10) that in the absence of NT, changing country j's domestic protection (Ω_{jj}) has *no direct effect* on country i's decision regarding its domestic protection (Ω_{ii}). This is not the case under NT, since a country cannot choose its domestic and foreign patent policies separately.

Following the above logic, the best response curve for country i's foreign protection, Ω_{ij}, can be obtained as

$$C_c - C_m = \frac{\gamma M_i}{M_i\Omega_{ij} + M_j\Omega_{jj}}[(C_m - C_c)\Omega_{ij} + C_c\overline{T}]. \tag{11}$$

[14]The second-order conditions can be shown to hold for both countries.

It is important to note from this first order condition that country i's marginal cost of strengthening its foreign protection Ω_{ij} is not mitigated by π, because the monopoly profits generated by extending such patent protection accrue to foreign firms. It follows that a country's marginal cost of foreign patent protection is necessarily larger than that of domestic protection, which is the sole reason for why it has an incentive to implement discriminatory patent policies (as shown below). It is also clear from (11) that Ω_{jj} and Ω_{ij} are substitutes for each other: if country j increases its domestic patent protection (Ω_{jj}) then country i will find it optimal to lower its foreign protection Ω_{ij}.

We can show the following:[15]

Proposition 1: *In the absence of NT, each country's patent policy discriminates in favor of domestic firms:* $\Delta\Omega_i^* \equiv \Omega_{ii}^* - \Omega_{ij}^* > 0$ *for* i, $j = H, F$.

Proposition 1 is similar in spirit to the findings of Horn (2006) and Saggi and Sara (2008) who focus on NT in the context of tax policies. In particular, they show that if NT is not binding then each country will tax foreign firms more severely because their profits do not count as part of national welfare. The logic here is the same: discriminatory patent policies arise naturally from the fact that countries care about profits accruing to domestic firms but not foreign ones. The key question that follows is whether eliminating such discrimination via NT brings about efficiency gains, which will be addressed in the analysis below.

Firms make R&D decisions based on the duration of patent protection in each country as well as its market size. The level of effective global protection received by firms from country i under discriminatory patent policies equals

$$P_i^* = M_i\Omega_{ii}^* + M_j\Omega_{ji}^*$$

where $i = H, F$. How does the level of effective global protection P_i^* vary with the national origin of firms? We can show the following:

Lemma 1: *When countries implement discriminatory patent policies, the effective patent protection available to firms is equal across countries:* $P_i^* = P^*$, $i = H, F$.

Lemma 1 implies that the incentives for innovation are the same for firms in either country. Intuitively, when country i protects its own firms more than country j protects its own firms – as would be true if the market size of country i is larger – then country i also protects foreign firms more than country j. Indeed, if country i is much larger than

[15] Proofs of all propositions that are not in the text are provided in the appendix.

country j, it is possible for it to grant better protection to foreign firms than they receive from their own government even when country i discriminates against foreign firms. Such international offsetting of patent protection equalizes incentives for innovation across countries.

Since

$$M_i \Omega_{ii}^* + M_j \Omega_{ji}^* = M_j \Omega_{jj}^* + M_i \Omega_{ij}^*,$$

it follows that

$$M_i \Delta\Omega_i^* = M_j \Delta\Omega_j^* \Leftrightarrow \Delta\Omega_i^* / \Delta\Omega_j^* = M_j / M_i$$

which we state as:

Proposition 2: *The relative degree of discrimination ($\Delta\Omega_i^*/\Delta\Omega_j^*$) practised by a country is inversely proportional to its relative market size (M_i/M_j), $i = H$, F.*

A country's weight in determining the level of effective global protection facing innovators increases with its own market size, as does the benefit it enjoys from foreign innovations. Therefore, the country with the larger market has a *weaker incentive to discriminate* against foreign nationals. As we noted in the Introduction, in typical models of international trade agreements, as a country gets larger (i.e. has more market power) it tends to typically increase discrimination against foreign sellers. By contrast, the opposite happens here: if one country gets larger, the other country benefits from a reduction in patent discrimination faced by its firms abroad as well as from an increase in the degree of global patent protection (which leads to more innovation).

3.2 Patent protection under NT

Now suppose that each country must choose a non-discriminatory patent protection level that applies to all innovating firms, regardless of national origin. A detailed analysis of the NT regime is provided in Grossman and Lai (2004). Here, we focus on comparing outcomes under NT with those under discrimination. The best response curve for country i under NT can be written as follows

$$C_c - C_m - \mu_i \pi = \gamma \frac{M_i}{P_i(\Omega_i, \Omega_j)} [(C_m - C_c)\Omega_i + C_c \overline{T}] \tag{12}$$

where $P_i(\Omega_i, \Omega_j) = M_i \Omega_i + M_j \Omega_j$ and $\mu_i = \frac{\phi_i^{NT}}{\phi_i^{NT} + \phi_j^{NT}}$ is the proportion of innovation that occurs in country i. Since the R&D production function is Cobb-Douglas in nature, it turns out that

$$\mu_i = \frac{K_i}{K_i + K_j} < 1$$

i.e., μ_i is determined solely by the relative human capital stocks of countries and is unaffected by their patent policies.

Observe from (10), (11), and (12) that country i's marginal cost of patent protection under NT is strictly in between the marginal costs of granting patent protection to domestic firms and foreign firms under discrimination:

$$C_c - C_m - \pi < C_c - C_m - \mu_i \pi < C_c - C_m.$$

This inequality follows from the fact that a country only cares about profits of local firms while NT forces it to treat all firms symmetrically. As a result, the profit of a typical innovating firm is discounted by μ_i, where which increases in its home country's human capital (K_i). This means that when a large share of the global innovation is carried out by local firms, the marginal cost of patent protection facing a country declines. In general, since NT forces countries into a scenario where the marginal cost of patent protection is a weighted average of the marginal costs associated with the discriminatory protection levels accorded to domestic and foreign firms, intuition suggests that NT might induce countries to select a level of protection that lies in the interval $(\Omega_{ii}, \Omega_{ij})$ – a conjecture we formally confirm below.

Proposition 3: *(i) Under NT, each country selects a level of patent protection that exceeds the protection it grants to foreign firms under discrimination but falls short of that which it gives to its domestic firms:* $\Omega^*_{ij} < \Omega^{NT}_i < \Omega^*_{ii}$ *for* $i, j = H, F$. *If countries are symmetric then* $2\Omega^{NT}_i = \Omega^*_{ii} + \Omega^*_{ij}$ *for* $i, j = H, F$.
(ii) The effective global protection available to firms as well as global welfare under NT is the same as that under discrimination: $P^{NT} = M_i \Omega^{NT}_i + M_j \Omega^{NT}_j = P^*$.

To see more explicitly why welfare under NT is the same as that under discrimination, from (6) we can rewrite world welfare under regime R as

$$\begin{aligned} WW^R &= \sum_i \Lambda_{i0} + \frac{1}{\rho} \sum_i w_i (L_i - L^R_{Ii}) \\ &\quad + \frac{C_c \overline{T}}{\rho} \sum_i \phi^R_i M_i - \sum_i \phi^R_i P^R_i \left[\frac{C_c - C_m - \pi}{\rho} \right]. \end{aligned}$$

Observe from this that in the absence of NT, world welfare depends only upon the effective protection levels $P^R_i = M_i \Omega^R_{ii} + M_j \Omega^R_{ji}$ available to firms from both countries under regime R (where $R = NT$ or D) since P_i^R pins down all the other endogenous variables such as the allocation of resources to R&D (L_{Ii}^R) and the rates of innovation (ϕ_i^R). But from Proposition 3 we already know that $P_i^* = P^{NT}$. As a result, world welfare is invariant to whether or not the underlying patent regime abides by NT.[16] Therefore, mandating NT is neither necessary nor sufficient for achieving efficiency provided international trade is not subject to any frictions.

The welfare neutrality of NT in our model is a rather novel finding in the context of the literature on NT. As we noted earlier, models in which NT applies to taxation typically find results favorable to NT. Further, even in the context of patent protection, in a two period model Bond (2005) has shown that, holding constant the level of patent protection given to domestic firms, eliminating discrimination against foreign firms raises global welfare. The driving force behind this result is as follows: since each country offers less patent protection to foreign firms, the switch from discrimination to NT holding domestic protections constant increases overall patent protection thereby alleviating the inefficiency caused by the under-protection of patents in the non-cooperative Nash equilibrium. But our analysis shows that since it is optimal for both countries to lower their domestic patent protection when each of them increases its patent protection towards foreign firms, NT by itself does not raise welfare since it leaves the effective protection levels facing innovating firms unchanged.

Grossman and Lai (2004) showed that the Nash equilibrium under NT gives rise to under-protection of intellectual property due to the positive international externalities generated by national patent protection policies. From the above analysis, it is not hard to see that the free rider problem that plagues the Nash equilibrium under NT continues to exist even when countries institute discriminatory patent policies. While there is under-protection of patent protection in our model as well, our analysis highlights that a move towards increasing patent protection to foreigners driven by NT does not occur in isolation since each country simultaneously lowers the protection it grants to domestic firms. In fact, changes in patent protection granted to domestic firms as a result of NT exactly offset the increased protection granted to foreign firms so that NT does not alter the effective global protection available to firms. In this way, our model is able to

[16] It is worth emphasizing that our model considers the simultaneous adoption of NT by both countries. One might also be interested in knowing the welfare consequences of a *unilateral violation* of NT by a single country, particularly since actual trade disputes among WTO members, particularly outside the realm of TRIPS, often involve a violation of the NT clause. We can show that given that country j abides by NT, a unilateral violation of NT by country i increases the effective global patent protection facing its firms while lowering that facing foreign firms, thereby increasing the rate of innovation in country i while lower it in country j.

separate the impact of NT on welfare from the increase in overall patent protection that results if NT is interpreted as a policy that brings up the patent protection granted to foreign nationals holding constant the protection granted to domestic firms.

4 NT in the presence of trade frictions

Since the welfare neutrality of NT in the benchmark model is driven by the *complete offsetting* of patent protection across countries when discriminatory policies are eliminated via NT, it is worth asking whether such international offsetting also obtains in the presence of trade barriers and/or frictions. We now address this issue and show that when trade frictions exist, NT induces incomplete offsetting of patent protection across countries and actually ends up *lowering* the effective level of global patent protection.

4.1 Trade frictions and discrimination

Before deriving the effect of trade frictions on the incentives for discrimination in patent protection, we make three simple observations. First, trade frictions reduce the surplus consumers derive from foreign goods. Second, by making it costlier for firms to export, trade frictions lower export profits of firms (while having no effect on their domestic profits).[17] Third, trade frictions do not affect the surplus consumers derive from goods whose patents have expired, regardless of where they were invented, since imitated goods are produced locally in each market so that there is no trade in such goods.

Denote the (inverse of) the degree of trade frictions between countries by θ, where $0 \leq \theta \leq 1$ and $\theta = 1$ represents free/costless trade while $\theta = 0$ indicates the complete absence of trade. In the presence of trade frictions, denote the consumer surplus derived from a patented imported good by θC_m while the export profits earned by a firm by $\theta\pi$. This parsimonious formulation of trade frictions (i.e. as being captured by a single parameter θ) is adopted purely for expositional simplicity.[18] Our results below hold as

[17] Trade frictions do not affect domestic profits since each firm selling a patented product is a monopoly in its local market.

[18] If $h(x) = \zeta^{1/\varepsilon}\frac{\varepsilon}{\varepsilon-1}x^{\frac{\varepsilon-1}{\varepsilon}}$ where $\varepsilon > 1$ and $\zeta > 0$ and trade barriers are of the ice-berg type, then it is straightforward to show that consumer surplus from imports and overseas profits earned by firms equal θC_m and $\theta\pi$ respectively, where $\theta = (1+t)^{1-\varepsilon}$ is the inverse measure of trade frictions and $t > 0$ is the ice-berg type trade cost. Lai and Yan (2013) embed this formulation of trade costs in a model of patent protection with firm heterogeneity and FDI and show that trade liberalization helps alleviate the problem of under-protection in Nash equilibrium. Even in their model, trade frictions lower overseas profits and consumer surplus derived from imported goods. Thus, allowing for firm heterogeneity and FDI does not affect the main channel that renders foreign patent protection less effective than domestic

long as trade frictions lower the consumer surplus derived from foreign goods and the export profits of innovating firms, even if they do so in a non-linear fashion and/or at very different rates. All we require is that the due to the presence of trade frictions, the (per-capita) consumer surplus derived from imports be lower than that derived from locally produced goods and that the export profits (per-capita) of a firm be smaller than its domestic profits.

It is worth noting that in the context of patent protection, a world with prohibitive trade frictions ($\theta = 0$) is not the same as one in which the two economies are fully autarkic in the sense of being completely shut off from each other. In particular, if technology transfer does not depend on trade (i.e. if ideas can flow across national borders without trade in goods – see Rivera-Batiz and Romer, 1991), then a country can imitate foreign goods even in the complete absence of international trade (i.e. $\theta = 0$). As a result, one would expect a country to have less incentive to protect intellectual property when $\theta = 0$ relative to the autarky case. Indeed it is possible to show, for example, that patent protection under NT when $\theta = 0$ is lower in both countries relative to the autarkic level.

The key question we address below is: How do trade frictions affect incentives for discrimination? The overseas profit earned by a firm from country i equals $\theta M_j \Omega_{ji} \pi$ so that the corresponding firm value equals

$$v_i^D(\theta) = (M_i \Omega_{ii} + \theta M_j \Omega_{ji})\pi.$$

As is clear from above, due to the presence of trade frictions ($\theta < 1$) patent protection in export markets (i.e. Ω_{ji}) is relatively *less valuable* for firms than protection in their domestic markets (i.e. Ω_{ii}).

Now consider country i's decision regarding patent protection. The marginal cost of extending domestic protection remains unchanged relative to free trade since trade frictions do not affect the consumption of domestic goods and the profit firms make in their domestic markets. A country's marginal benefit of domestic protection, however, is different as trade frictions do affect the value of domestic firms by reducing their export profits and therefore the influence of foreign patent protection Ω_{ji} on their innovation incentives.

The marginal benefit of extending domestic protection Ω_{ii} equals

$$\frac{1}{\rho} \frac{\gamma \phi_i^D M_i^2}{M_i \Omega_{ii} + \theta M_j \Omega_{ji}} [(C_m - C_c)\Omega_{ii} + C_c \overline{T}].$$

Note that holding constant Ω_{ji} (i.e. the protection domestic firms get abroad), the marginal benefit of increasing Ω_{ii} (i.e. the protection to domestic firms) decreases with

protection in our model.

θ. All else equal, a reduction in trade frictions makes Ω_{ji} a more effective substitute for Ω_{ii} due to increased export profits of firms.

Country i's best response curve for domestic protection Ω_{ii} can be written as

$$C_c - C_m - \pi = \frac{\gamma M_i}{M_i\Omega_{ii} + \theta M_j\Omega_{ji}}[(C_m - C_c)\Omega_{ii} + C_c\overline{T}]. \tag{13}$$

Regarding the protection extended to foreign firms, note that consumers in country i only derive a surplus of θC_m units from buying a patented foreign good. Since consumers always buy the good from domestic imitators once the patent expires, the corresponding surplus post imitation equals C_c. Thus, the marginal cost of raising foreign protection equals

$$\frac{M_i\phi_j^D(C_c - \theta C_m)}{\rho}.$$

As is clear, holding constant the rate of innovation, the marginal cost of protecting foreign firms increases with trade frictions.

Country i's marginal benefit of protecting foreign firms can be written as

$$\frac{1}{\rho}\frac{\gamma\theta\phi_j^D M_i^2}{\theta M_i\Omega_{ij} + M_j\Omega_{jj}}[(\theta C_m - C_c)\Omega_{ij} + C_c\overline{T}].$$

Note that holding constant Ω_{jj} (i.e. the protection foreign firms get from their own government), the marginal benefit of increasing Ω_{ij} (i.e. the protection given by country i to foreign firms) increases as trade frictions fall.

The best response curve for Ω_{ij} is given by

$$C_c - \theta C_m = \frac{\gamma\theta M_i}{\theta M_i\Omega_{ij} + M_j\Omega_{jj}}[(\theta C_m - C_c)\Omega_{ij} + C_c\overline{T}]. \tag{14}$$

Using the above best response curves, we can show the following:

Proposition 4: *As trade frictions between countries fall (i.e. θ increases), each country increases the degree of patent protection granted to foreign firms $\Omega_{ij}^*(\theta)$ while decreasing that granted to domestic firms $\Omega_{ii}^*(\theta)$. Furthermore, a reduction in trade frictions increase the degree of effective global patent protection in both countries, i.e., $\frac{\partial P_i^*(\theta)}{\partial\theta} > 0$ where $P_i^*(\theta) = M_i\Omega_{ii}^*(\theta) + \theta M_j\Omega_{ji}^*(\theta)$.*

We now compare NT and discrimination in the presence of trade frictions. As before, a typical firm's value under the NT regime equals

$$v_i^{NT}(\theta) = (M_i\Omega_i + \theta M_j\Omega_j)\pi.$$

It is important to note that due to the existence of trade frictions, v_i will in general be different from v_j even under NT, which further implies that firms in different countries may face different levels of effective patent protection.[19]

Under NT, the cost and benefit of a marginal change in patent protection depend upon the level of trade frictions. As the derivation is similar to before, we simply report country i's best response curve for Ω_i without presenting the relevant details:

$$\begin{aligned} C_c - (\mu_i + \theta\mu_j)C_m - \mu_i\pi &= \frac{\gamma M_i\mu_i}{M_i\Omega_i + \theta M_j\Omega_j}[(C_m - C_c)\Omega_i + C_c\overline{T}] \\ &\quad + \frac{\gamma\theta M_i\mu_j}{\theta M_i\Omega_i + M_j\Omega_j}[(\theta C_m - C_c)\Omega_i + C_c\overline{T}]. \end{aligned} \tag{15}$$

In section 4.2, we investigate the efficiency impact of NT. To facilitate this analysis, we assume that countries are symmetric in all respects ($M_i = M_j = M$, $K_i = K_j = K$ and $a_i = a_j = a$). This is a useful simplification for three reasons. First, it helps isolate the effect of trade frictions on the international patent regimes. Second, the issue of non-discrimination is as relevant, if not more, in a North-North type setting of relatively similar countries as it is in a North-South setting where there are significant differences across countries with respect to market size and human capital. Third, although analytical solutions under NT are difficult to calculate when countries are asymmetric in section 4.3, we analyze the social planner's problem and show that the key argument in favor of discrimination does not rest on the assumption of symmetry. Finally, in section 5.1, we use numerical examples to study Nash equilibrium outcomes under asymmetry and show that our result that the equilibrium under discrimination is more desirable does not require symmetry.

4.2 Effective patent protection

Denote the symmetric Nash equilibrium level of patent protection under NT by $\Omega^*(\theta)$. Under discrimination, let $\Omega_d^*(\theta)$ be the patent protection granted by each country to domestic firms and $\Omega_f^*(\theta)$ that given to foreign firms. We can then show the following:

Proposition 5: *Suppose countries are symmetric and there exist trade frictions between them (i.e. $0 \leq \theta < 1$). Then the following hold:*
(i) The degree of effective global protection received by firms under NT is lower than that under discrimination:

$$P^{NT}(\theta) = M(1+\theta)\Omega^*(\theta) < P^*(\theta) = M(\Omega_d^*(\theta) + \theta\Omega_f^*(\theta)).$$

[19] Recall that when trade is free, all firms receive the same effective level of global patent protection under NT.

(ii) The gap between the degree of effective patent protection under discrimination and NT decreases as trade frictions fall (i.e. $P^*(\theta) - P^{NT}(\theta)$ declines with θ).[20]

When trade frictions exist, from the viewpoint of firms, protection abroad matters less for profitability than protection at home. As a result, trade frictions make foreign protection relatively less effective in inducing innovation in each country. However, NT forces each country to treat firms the same even though their innovation incentives respond more to domestic protection. As a result, *NT blunts the effectiveness of patent protection for incentivizing innovation* so that, in equilibrium, the effective degree of protection chosen by countries under NT ends up being lower. This result is important because it shows that while there is under-protection of intellectual property under both NT and discrimination in our model, this problem is *more* severe under NT. Thus, somewhat paradoxically, in the presence of trade frictions allowing countries to discriminate against foreign nationals with respect to patent protection actually leads to stronger innovation incentives in the global economy.

The intuition behind Proposition 5 can also be understood by examining the marginal benefit and cost of strengthening patent protection. Suppose that $P^{NT}(\theta) \geq P^*(\theta)$. Then from the right-hand sides of (A6) and (A7) in the Appendix, we can see that the marginal benefit of patent protection is larger under discrimination for both countries. Moreover, it exceeds the marginal cost of patent protection so that each country would want to increase its total patent protection. This implies that $P^{NT}(\theta) \geq P^*(\theta)$ cannot be sustained as a Nash equilibrium. As a result we must have $P^*(\theta) > P^{NT}(\theta)$.

We now consider the problem of choosing jointly (or socially) optimal domestic and foreign patent protection for country i's firms (i.e. Ω_{ii} and Ω_{ji}).

4.3 Social welfare

The jointly optimal policies solve

$$\underset{\Omega_{ii},\, \Omega_{ji}}{Max}\ WW^D(\theta) \text{ where } WW^D(\theta) \ = \sum_i W_i^D(\theta).$$

To derive the first order conditions for this problem, it is useful to separately consider the *social* marginal benefits and costs of patent protection in each country. Following our previous discussion, the social marginal cost of domestic patent protection in country i

[20] In section 7.7 of the appendix we show that Propositions 5 and 6 also hold for the case of n countries, where $n > 2$.

(i.e. Ω_{ii}) equals

$$\frac{1}{\rho}\phi_i^D M_i(C_c - C_m - \pi) \tag{16}$$

while the social marginal benefit is

$$\frac{\gamma}{\rho}\frac{\phi_i^D M_i}{P_i}[(C_m - C_c)(M_i\Omega_{ii} + M_j\Omega_{ji}) + (M_i + M_j)C_c\overline{T} - (1-\theta)C_m M_j\Omega_{ji}] \tag{17}$$

where $P_i = M_i\Omega_{ii} + \theta M_j\Omega_{ji}$.

Analogously, we can write the social marginal cost and benefit of Ω_{ji} as

$$\frac{1}{\rho}\phi_i^D M_j(C_c - \theta C_m - \theta\pi) \tag{18}$$

and

$$\frac{\gamma}{\rho}\frac{\phi_i^D M_j\theta}{P_i}[(C_m - C_c)(M_i\Omega_{ii} + M_j\Omega_{ji}) + (M_i + M_j)C_c\overline{T} - (1-\theta)C_m M_j\Omega_{ji}]. \tag{19}$$

respectively. Observe from (18) that when calculating the social cost of extending patent protection to foreign firms in country i, the social planner accounts for the export profits earned by these firms, which is why the term $\theta\pi$ appears in (18) but not in equation (14).

We can write the first order conditions for Ω_{ii} and Ω_{ji} by equating the respective marginal cost of each type of protection to its marginal benefit. For Ω_{ii} we have

$$C_c - C_m - \pi = \frac{\gamma}{P_i}[(C_m - C_c)(M_i\Omega_{ii} + M_j\Omega_{ji}) + (M_i + M_j)C_c\overline{T} - (1-\theta)C_m M_j\Omega_{ji}] \tag{20}$$

while for Ω_{ji} it is

$$\begin{aligned} & C_c - C_m - \pi + \frac{1-\theta}{\theta}C_c \\ = \; & \frac{\gamma}{P_i}[(C_m - C_c)(M_i\Omega_{ii} + M_j\Omega_{ji}) + (M_i + M_j)C_c\overline{T} - (1-\theta)C_m M_j\Omega_{ji}]. \end{aligned} \tag{21}$$

Note that for all $\theta < 1$ the right-hand sides of both FOCs are the same, but the left-hand side of (21) is larger. This implies that, except for the extreme case where each country is at a corner solution, both FOCs cannot hold simultaneously. In particular, if $\Omega_{ii} < \overline{T}$ (i.e. (20) holds), then it must be that (21) does not hold so that $\Omega_{ji} = 0$.[21] We can now state:

[21] The case where $\Omega_{ii} = \overline{T}$ is discussed in the appendix.

Proposition 6: *In the presence of trade frictions (i.e. $\theta < 1$), social optimality calls for each country to discriminate against foreign firms, i.e. $\Omega^w_{ij} < \Omega^w_{ii}$ for $i, j = H, F$.*[22] *Furthermore, if it is optimal to offer firms less protection in their domestic markets than the useful lifetime of products (i.e. $\Omega^w_{ii} < \overline{T}$), then it is optimal to give them no patent protection in their export markets (i.e. $\Omega^w_{ji} = 0$).*[23]

In fact, for the case where markets are symmetric ($M_i = M_j = M$), we can use the first order condition in (20) and (21) to write

$$\frac{\partial WW^D(\theta)}{\partial \Omega_{ii}} - \frac{1}{\theta}\frac{\partial WW^D(\theta)}{\partial \Omega_{ji}} = \frac{\phi^D_i M(1-\theta)C_c}{\theta} > 0 \text{ for all } 0 < \theta < 1, \qquad (22)$$

This equation explicitly shows that the net marginal social benefit of extending domestic patent protection to firms is strictly higher than the marginal benefit of foreign patent protection so long as their exist trade frictions between countries. Observe that this holds even when the human capital stocks of the two countries are unequal.

The central point of Proposition 6 is that trade frictions drive a wedge between the social value of domestic and foreign patent protections and social optimality calls for assigning a higher priority to domestic protection in each country. In other words, from the perspective of joint welfare, we care not only about the *level* of patent protection but also its *composition* across countries. In contrast, Grossman and Lai (2004) show that, under free trade, efficiency depends only on the level of total patent protection in the global economy and not on its composition across countries. In our model, this is easily verified by taking $\theta = 1$ in (22), so that domestic and foreign protections have equal net benefit. Proposition 6 shows that, in the realm of patent protection, the presence of trade costs makes it socially optimal to discriminate in favor of local innovators in each country. It is noteworthy that such discrimination is desirable even when beggar-thy-neighbor incentives are completely missing (as they are when countries maximize joint welfare).

Bond (2005) has shown that it can be socially optimal to globally discriminate in favor of firms from one country provided the elasticity of innovation in that country with

[22] Since under this scheme of jointly optimal protection firms receive less protection abroad than they do at home, for any given innovation, foreign consumers begin to enjoy greater surplus (arising from local imitation) sooner than domestic ones. Indeed, if markets are unequal in size we can show that the degree of jointly optimal protection for firms in each country is increasing in the relative size of the other country's market: $\frac{\partial \Omega^w_{ii}}{\partial (M_j/M_i)} > 0$.

[23] A corner solution for foreign protection might not arise if there exist enforcement costs that are increasing in the level of patent protection. Under such costly enforcement, foreign protection may be utilized even if domestic protection does not reach the boundary $\overline{T}$. Even so, the rationale for discrimination would remain since such enforcement costs would presumably also apply to foreign protection, and might even be higher than those for domestic protection.

respect to patent protection is relatively higher. Note, however, that Bond's analysis provides conditions under which it is socially optimal to provide favorable treatment to firms from one country in *both* countries whereas we consider whether it can ever be optimal to have firms from both countries enjoy favorable treatment in their respective domestic markets, an inquiry that is more in line with the actual spirit behind the national treatment clause. Furthermore, our analysis shows that the mere existence of trade barriers is sufficient to make such type of discrimination socially desirable; one does not need the elasticity of innovation with respect to patent protection to be unequal across countries, although that could be an additional contributing factor in our framework as well if our model were extended to incorporate it.

An interesting implication of the presence of trade frictions is that it socially desirable to discriminate more in favor of goods that are harder to trade. Specifically, in the extreme hypothetical case where all goods are non-tradable (i.e. $\theta = 0$), there would be no reason to protect foreign firms at all since their innovation incentives would be unresponsive to patent protection granted by countries other than their own. Indeed, if $\theta = 0$ protecting foreign innovations would only delay domestic consumption of newly invented foreign goods by the duration of the patent without affecting the foreign rate of innovation.

Comparing the first-order conditions determining the Nash equilibrium with those under joint welfare maximization, it is easy to see that the marginal cost of patent protection under the Nash equilibrium (as perceived by each country) is no less than the true social cost while the marginal benefit of such protection is smaller if effective protection under the two scenarios is the same (i.e. if $M_i\Omega_{ii}^w = M_i\Omega_{ii}^* + \theta M_j\Omega_{ji}^*$). Thus, in an interior solution we must have $M_i\Omega_{ii}^* + \theta M_j\Omega_{ji}^* < M_i\Omega_{ii}^w$, i.e. there is under-protection in Nash equilibrium even in the presence of trade frictions, although the magnitude of the externality from foreign protection is reduced. Another interesting observation about discriminatory patent policies is that while coordination always leads to weaker foreign protection, in an asymmetric Nash equilibrium a country's foreign protection can actually exceed the foreign country's domestic protection. This is because the larger country tends to discriminate less while the smaller country tends to free ride more. Notably, even though the smaller country may be "sheltered" by the policies of the larger one, Proposition 6 indicates that this is not justified from an efficiency point of view.

5 Further analysis

In this section, we extend our model in two directions. First, we examine the effects of NT in a North-South setting where countries are asymmetric with respect to market size and/or their human capital stocks. Second, to capture the effects of trade policy variables, we consider a setting where the degree of trade openness facing firms depends upon their national origin – i.e. the access enjoyed by firms from country i to country j's market is not necessarily the same as that enjoyed by firms from country j to country i's market. The analysis of this scenario allows us to address how the incentives for discrimination vary with domestic and foreign trade policies.

5.1 NT in a North-South setting

In this sub-section, we discuss how the relative performance of NT and discrimination depends upon the degree of asymmetry across countries. This issue is important because what made TRIPS negotiations especially difficult was the clash between the views of developing and developed countries regarding the desirability of multilateral disciplines in the area of intellectual property. Furthermore, since WTO members differ markedly in terms of their economic capabilities and factor endowments, it is important to know how NT operates in such an environment. Section 4.3 showed that, in the presence of trade frictions, if patent policies are chosen to maximize joint welfare then NT is less efficient than discrimination, regardless of the degree of asymmetry across countries. What is interesting to know is whether this is also true in a noncooperative Nash equilibrium when countries are asymmetric in terms of economic fundamentals and there is no policy coordination between them.

In particular, it seems useful to consider a North-South scenario where the North's market as well as the stock of its human capital is larger than that of the South: i.e. $M_i > M_j$ and $K_i > K_j$.[24] The non-linearity of first order conditions (FOCs) under NT (see (15)) makes it difficult to obtain analytical solutions under asymmetry. Nevertheless, we show below that the key driving forces behind NT being efficiency-reducing relative to discrimination continue to operate in a North-South setting. To this end, adding up

[24] One may also assume that the North has higher labor productivity (i.e. $a_i < a_j$), but this will not change our analysis in a substantive way.

FOCs for both countries under NT yields

$$2C_c - (1+\theta)C_m - \pi = \gamma[\frac{\mu_i}{P_i^{NT}(\theta)}[(C_m - C_c)P_i^{NT}(\theta) + (M_i + \theta M_j)C_c\overline{T} \\ -(1-\theta)\theta M_j \Omega_j(\theta)] + \frac{\mu_j}{P_j^{NT}(\theta)}[(C_m - C_c)P_j^{NT}(\theta) \\ +(M_j + \theta M_i)C_c\overline{T} - (1-\theta)\theta M_i \Omega_i(\theta)]]. \tag{23}$$

Similarly, adding the two FOCs under discrimination yields

$$2C_c - (1+\theta)C_m - \pi = \gamma[\frac{1}{2P_i(\theta)}(C_m - C_c)P_i(\theta) + (M_i + \theta M_j)C_c\overline{T} \\ -(1-\theta)\theta M_j \Omega_{ji}(\theta)] + \frac{1}{2P_j(\theta)}[(C_m - C_c)P_j(\theta) \\ +(M_j + \theta M_i)C_c\overline{T} - (1-\theta)\theta M_i \Omega_{ij}(\theta)]]. \tag{24}$$

Note that the left hand-side of both FOCs can be interpreted as the global marginal cost of patent protection, as it is the sum of marginal costs of patent protection across countries. Analogously, the right hand-side of both FOCs represents the global marginal benefit of patent protection. Observe that while the global marginal cost of patent protection under the two regimes is the same (since the left-hand sides of the two FOCs are identical), the global marginal benefit is not. Indeed, the global marginal benefit of patent protection under NT is lower than that under discrimination. This is because NT forces countries to overuse foreign protection when trade is subject to frictions, which other things being equal, tends to reduce the global marginal benefit of patent protection. Recall that this overuse of foreign protection under NT was the key driving force behind our analysis of the symmetric case so it is not surprising that this mechanism continues to exist under asymmetry. Indeed, observe that the incentive-reducing effects of trade frictions under NT, captured by the terms $(1-\theta)\theta M_i\Omega_i(\theta)$ and $(1-\theta)\theta M_j\Omega_j(\theta)$ in (23), are larger than those under discrimination, captured by the terms $(1-\theta)\theta M_i\Omega_{ij}(\theta)$ and $(1-\theta)\theta M_j\Omega_{ji}(\theta)$. This is because $\Omega_i(\theta) > \Omega_{ij}(\theta)$ and $\Omega_j(\theta) > \Omega_{ji}(\theta)$ in equilibrium.[25] Intuitively, when countries consider raising domestic patent protection under NT, they

[25] We have shown this is true under free trade, that is, $\Omega_i^{NT}(\theta) > \Omega_{ij}^*(\theta)$ and $\Omega_j^{NT}(\theta) > \Omega_{ji}^*(\theta)$ when $\theta = 1$. As θ falls, both $\Omega_{ij}^*(\theta)$ and $\Omega_{ji}^*(\theta)$ decrease. Indeed, the marginal benefit of extending patent protection to foreigners becomes infinitesimally small as θ approaches zero (see the right hand-side of (14)). This is not true for $\Omega_i^{NT}(\theta)$ and $\Omega_j^{NT}(\theta)$ since the marginal benefit of patent protection under NT has a positive lower bound due to the fact that such protection also extends to domestic firms and part of their innovation incentive stems from domestic profits that remain unaffected by trade barriers (see the right hand-side of (15)). Therefore, $\Omega_i^{NT}(\theta)$ and $\Omega_j^{NT}(\theta)$ cannot be lower than $\Omega_{ij}^*(\theta)$ and $\Omega_{ji}^*(\theta)$.

are more conscious of the negative incentive effects of trade frictions since the level of foreign protection has to raised by the same amount.

It is also worth noting that, as shown in section 2, the above distortion generated by NT readily disappears when trade fractions vanish. When $\theta = 1$ domestic and foreign protections are equally effective so that the incentive-reducing terms in both (23) and (24) drop out.

We conducted numerical simulations to further study NT under asymmetry. We now briefly discuss the results of this analysis. For simplicity, we consider a constant elasticity demand function ($x = p^{-\varepsilon}$ where $\varepsilon = 1.5$). With this specific demand function it can be shown that $C_m = \pi \approx 0.2Cc$. Also, we assigned the following values to the fundamental parameters of the model: $\alpha = 0.67$, $\gamma = 3$, $C_c = 5$ and $\overline{T} = 20$. Let $\rho \simeq 1$ without loss of generality. These parameter values ensure interior solutions under discrimination and NT and our results are robust to variations in them. To normalize away any level effects, we fix the total world market size $(M_i + M_j)$ and the stock of human capital $(K_i + K_j)$.

[Figure 1 here]

Figure 1 shows how the welfare difference between discrimination and NT, i.e. $(WW^D - WW^{NT})/WW^{NT}$, varies with trade frictions θ, given $M_i = 10$, $M_j = 5$, $K_i = 2$ and $K_j = 1$. First note that so long as trade frictions exist $(\theta < 1)$, discrimination generates strictly higher welfare than NT regardless of the level of such frictions. This is consistent with our results regarding the negative effects of NT under the presence of trade frictions. Moreover, as trade frictions fall (i.e. θ increases), the welfare differential between the two regimes converges to zero.

Table 1 compares the levels of total effective patent protection and national welfare across the two regimes for three different levels of trade frictions. First note that the level of patent protection under NT lies in between the two discriminatory protections regardless of the level of trade frictions (i.e. $\Omega_i^{NT}/\Omega_{ii}^* < 1 < \Omega_i^{NT}/\Omega_{ij}^*$). This verifies the distortion that NT causes by the excessive use of foreign protection. Using the first four columns of Table 1, it is easy to confirm that countries tend to discriminate less as trade frictions fall – i.e. $\Omega_{ij}^*/\Omega_{ii}^*$ and $\Omega_{jj}^*/\Omega_{ji}^*$ both decrease with θ – which is consistent with Proposition 4. Note also that the North (i.e. country i) is worse-off under NT even if it receives more total effective protection under NT relative to discrimination: i.e. $W_i^{NT}/W_i^D < 1$ even though $P_i^{NT}/P_i^D > 1$. The reason is that the South (i.e. country j) under-innovates due to it receiving lower effective protection under NT relative to discrimination, generating a large welfare loss for the North that ends up offsetting the benefit conferred by the higher degree of effective protection received by its firms under NT. Finally, the last two columns of Table 1 show that the welfare loss imposed on each country by NT increases with the level of trade frictions.

[Table 1 here]

To see how the welfare gap between NT and discrimination is affected by the degree of asymmetry between the two countries, we studied the effects of changes in their relative market size and human capital stocks. We first set $K_i = K_j = 1$ and $\theta = 0.75$ and considered the effects of reducing the gap between M_i and M_j in the above experiment to 0, fixing their sum (at 20). *Figure 2 shows that the welfare loss from NT is smaller when countries are more asymmetric in terms of market size.* To understand the intuition behind this result, recall from Proposition 2 that a country's incentive for discrimination is inversely related to its market size. Since an increase in market size asymmetry reduces discrimination in the larger market while it raises it in the smaller market, the average degree of discrimination *declines* in our model as markets become more unequal in size. For analogous reasons, the degree of effective global protection increases with market size asymmetry. Thus, *the global welfare loss generated by NT declines as markets become more unequal in size.* This finding suggests that the NT discipline may be a smaller concern in a North-South setting.

[Figure 2 here]

Finally, we illustrate the effects of asymmetric human capital stocks. To this end, we equalize market size across countries by setting $M_i = M_j = 7.5$ and bring K_i and K_j closer to 1.5 from 2 and 1 respectively. Again, we see in Figure 3 that NT generates a smaller welfare loss when human capital stocks are less equal across countries. The intuition is different from that in the case of market asymmetry, however, as we have shown that relative capital stock does not affect a country's tendency for discrimination. To see what drives our results, note that the North chooses stronger patent protection under NT as its human capital stock increases, since it is able to capture a larger share of global profits that result from innovation. In the meantime, Northern firms receive more total protection since the major component of their overall protection is Northern protection and the increase in such protection is not discounted by the level of trade frictions (θ). As a result, the North has a stronger incentive for innovation under NT, a pattern that promotes innovation and welfare. This helps explain why welfare under NT is higher when the distribution of human capital stock is more unequal across countries (although welfare under NT is still lower than that under discrimination).

[Figure 3 here]

To check the robustness of our findings, we also conducted further numerical analysis by varying relative market size and human capital stock simultaneously. Figure 4 plots the relative welfare difference between discrimination and NT for one such simulation. We utilize the same parameter values as Figure 1 and set $\theta = 0.75$. In the figure, the horizontal axes represent the two country characteristics of interest, each varying from 0.5 (very asymmetric) to 1 (symmetric). The first observation is that discrimination yields higher world welfare regardless of the degree of asymmetry, as illustrated by the welfare difference plane which lies above zero everywhere. Moreover, as can be seen from Figure 4, the welfare difference between NT and discrimination becomes larger as countries become more alike in either characteristic (i.e. market size or human capital). In particular, the plane peaks at the upper-right hand corner where both market size and human capital stock are equal across countries.

[Figure 4 here]

5.2 Trade barriers and patent protection

Our analysis thus far assumes symmetric trade barriers in both directions since a single parameter θ captures the degree of trade openness of both countries. This approach is reasonable when trade frictions reflect underlying structural parameters such as transportation costs but is on weaker grounds if such frictions arise from tariffs and other trade policy barriers which can, and do, differ across countries. To understand how changes in national trade policies affect incentives for patent protection, we now extend our model to allow for the presence of asymmetric trade barriers. Let θ_i be the trade barriers facing imports flowing into country i, where an increase in θ_i implies unilateral trade liberalization on the part of country i. As before, such liberalization increases the export profits of country i's firms as well as the surplus consumers in country i derived from imported goods.

In the absence of NT, country i's FOCs for patent protection under asymmetric trade barriers can be written as

$$C_c - C_m - \pi = \frac{\gamma M_i}{M_i \Omega_{ii} + \theta_j M_j \Omega_{ji}} [(C_m - C_c)\Omega_{ii} + C_c \overline{T}], \tag{25}$$

and

$$C_c - \theta_i C_m = \frac{\gamma \theta_i M_i}{M_j \Omega_{jj} + \theta_i M_i \Omega_{ij}} [(\theta_i C_m - C_c)\Omega_{ij} + C_c \overline{T}] \tag{26}$$

Country j's FOCs can be obtained by simply switching i and j.

To isolate the role of national trade barriers, we assume countries are symmetric in terms of market size and human capital. Given this, it can then be shown that country i's equilibrium levels of patent protections under discrimination are

$$\Omega_{ii}(\theta_i, \theta_j) = \frac{C_c \overline{T}[(1 + \gamma - \theta_j)C_c - \gamma\theta_j C_m + \theta_j \pi]}{(C_c - \theta_j C_m)[(2 + \gamma)(C_c - C_m) - \pi]} \tag{27}$$

and

$$\Omega_{ij}(\theta_i, \theta_j) = \frac{C_c \overline{T}[(\theta_i + \gamma\theta_i - 1)C_c - \gamma\theta_i C_m - \theta_i \pi]}{\theta_i(C_c - \theta_i C_m)[(2 + \gamma)(C_c - C_m) - \pi]} \tag{28}$$

Consider now the effects of unilateral trade liberalization by country i on its own patent policies when it is free to implement discriminatory patent policies. Using (27) we have

$$\frac{\partial \Omega_{ii}(\theta_i, \theta_j)}{\partial \theta_i} = 0 \tag{29}$$

and

$$\frac{\partial \Omega_{ij}(\theta_i, \theta_j)}{\partial \theta_i} = \frac{C_c \overline{T}[\theta_i^2 C_c C_m + \gamma\theta_i^2 C_c C_m - 2\theta_i C_c C_m - \pi\theta_i^2 C_m - \gamma\theta_i^2 C_m + C_c^2]}{\theta_i^2 (C_c - \theta_i C_m)^2 [(2 + \gamma)(C_c - C_m) - \pi]} > 0 \tag{30}$$

i.e., a reduction in own trade barriers does not affect country i's domestic protection but it increases the patent protection it grants to foreign innovators. Thus, own trade liberalization makes a country less willing to discriminate against foreign innovators with respect to its patent policies. The intuition is straightforward: since neither the profits of domestic innovators nor the surplus consumers enjoy from local goods depends upon local trade barriers, the value of patent protection granted to local firms is independent of local trade barriers.[26] On the other hand, the reduction of trade barriers by country i increases the profits foreign innovators derive from its market while also increasing the surplus consumers derive from foreign innovations. Both these factors increase the value of foreign innovations to country i, making it optimal to offer stronger patent protection to foreign innovators.

Note further that country i's domestic protection falls with foreign trade liberalization:

$$\frac{\partial \Omega_{ii}(\theta_i, \theta_j)}{\partial \theta_j} = -\frac{C_c^2 \overline{T}(C_c - C_m - \pi)}{(C_c - \theta_j C_m)^2 [(2 + \gamma)(C_c - C_m) - \pi]} < 0 \tag{31}$$

[26] This result is driven by the fact that there is no product market competition in our model since each new differentiated good is unrelated to existing goods (i.e. is produced by a true monopolist).

The intuition for this is that since $\frac{\partial \Omega_{ji}(\theta_i,\theta_j)}{\partial \theta_j} > 0$ (i.e. country j's foreign protection increases with its trade liberalization) and patent protection policies are strategic substitutes across countries, it is optimal for country i to lower the protection it extends to domestic firms when they start receiving more protection abroad. Finally, since country j's trade barriers affect neither consumers surplus in country i nor the profits of firms from country j in country i, we have:

$$\frac{\partial \Omega_{ij}(\theta_i,\theta_j)}{\partial \theta_j} = 0 \tag{32}$$

Let $\Delta\Omega_i(\theta_i,\theta_j) = \Omega_{ii}(\theta_i,\theta_j) - \Omega_{ij}(\theta_i,\theta_j)$ measure the degree of patent discrimination practised by i. It follows immediately from our results above that trade liberalization by either country reduces the degree of discrimination practised by both countries, i.e.

$$\frac{\partial \Delta\Omega_i(\theta_i,\theta_j)}{\partial \theta_i} < 0 \tag{33}$$

and

$$\frac{\partial \Delta\Omega_i(\theta_i,\theta_j)}{\partial \theta_j} < 0 \tag{34}$$

An important implication of (33) and (34) is that global trade liberalization makes countries less resistant to accepting NT with respect to their patent policies.

6 Conclusion

The TRIPS agreement was controversial from the start. Developing countries fought hard against the inclusion of any multilateral agreement on intellectual property in the WTO, just as major developed countries put their considerable weight behind it. In addition to increasing the level of intellectual property protection in developing countries, TRIPS made it illegal for WTO members to discriminate against foreign nationals via the NT principle.

At first glance, the inclusion of a non-discrimination principle in TRIPS hardly seems worthy of comment. After all, the idea of non-discrimination is the very foundation of the multilateral trading system. Yet, our analysis has shown that the desirable properties of NT in the context of trade in goods do not extend automatically to the domain of intellectual property.

The key driving force behind our results is that incentives for innovation depend upon the overall patent protection firms receive in the global economy and the composition of such protection matters only when international market access is hampered by trade frictions. Absent such frictions, NT is inconsequential since what firms lose abroad is offset by what they gain at home. While we focus mostly on a two-country setting, we show that the key driving force behind our analysis carry over to a multi-country scenario.

When access to foreign markets is hampered by trade frictions (i.e. transportation costs and/or trade policy barriers), the case for non-discrimination in patent protection is even weaker. The intuition here is simple as it is undeniable: in the presence of trade frictions, substituting domestic patent protection for foreign protection affords innovating firms a higher level of effective patent protection because, all else equal, exports are less profitable than domestic sales. Furthermore, consumer welfare considerations reinforce this argument: trade frictions make foreign innovation relatively less valuable to domestic consumers in each country by making foreign goods costlier (or by reducing the volume of trade). As a result, in our model, imposing a NT constraint on national governments actually reduces global innovation and welfare in the presence of trade frictions.

Finally, it is important to recognize that our findings do not necessarily imply that NT should not have been included as a fundamental principle in TRIPS. Rather, we see our findings as highlighting one potential efficiency cost of NT that arises from the wedge that trade frictions create between the incentive effects of domestic and foreign patent protection. NT may yield other benefits that are not captured by our model, such as lower enforcement and implementation costs, greater consistency across international trade agreements, and potentially lower costs of international coordination across countries. Inclusion of these potential benefits of NT can make it more desirable than discrimination.

7 Appendix

7.1 Supporting calculations

Here we show that
$$\frac{\partial \phi_i}{\partial \Omega_{ii}} = \frac{\gamma \phi_i M_i}{M_i \Omega_{ii} + M_j \Omega_{ji}}$$
Note that $\frac{\partial \phi_i}{\partial \Omega_i^i} = \frac{\partial \phi_i}{\partial v_i} \times \frac{\partial v_i}{\partial \Omega_i^i}$. Hence, $\frac{\partial \phi_i}{\partial v_i} = \frac{\partial \phi_i}{\partial L_{Ii}} \frac{\partial L_{Ii}}{\partial v_i} = F_L^i \times \frac{\partial L_{Ii}}{\partial v_i}$. Differentiating the firm's FOC $v_i F_L^i = w_i$ w.r.t v_i we obtain $F_L^i + v_i F_{LL}^i \frac{\partial L_{Ii}}{\partial v_i} = 0$. This implies $\frac{\partial L_{Ii}}{\partial v_i} = -\frac{F_L^i}{v_i F_{LL}^i}$. Therefore, $\frac{\partial \phi_i}{\partial v_i} = -\frac{F_L^{i2}}{v_i F_{LL}^i} = -\frac{F_L^{i2}}{v_i F_{LL}^i \phi_i} \times \phi_i = \frac{\gamma}{v_i} \phi_i$ where $\gamma \equiv -\frac{F_L^{i2}}{F_{LL}^i \phi_i}$. Also note that $\frac{\partial v_i}{\partial \Omega_{ii}} = M_i \pi$. As a result, $\frac{\partial \phi_i}{\partial \Omega_{ii}} = \frac{\gamma}{v_i} \phi_i \times M_i \pi = \frac{\gamma \phi_i M_i}{M_i \Omega_{ii} + M_j \Omega_{ji}}$.

7.2 Proof of Proposition 1

Adding (10) and (11) for countries i and j respectively yields:

$$2(C_c - C_m) - \pi = \frac{\gamma}{M_i \Omega_{ii} + M_j \Omega_{ji}} [(C_m - C_c)(M_i \Omega_{ii} + M_j \Omega_{ji}) + (M_i + M_j) C_c \overline{T}], \quad \text{(A3)}$$

and

$$2(C_c - C_m) - \pi = \frac{\gamma}{M_j \Omega_{jj} + M_i \Omega_{ij}} [C_m - C_c)(M_j \Omega_{jj} + M_i \Omega_{ij}) + (M_i + M_j) C_c \overline{T}]. \quad \text{(A4)}$$

It is easy to see that the right-hand sides of (A3) and (A4) are monotonic functions of total protections $M_i \Omega_{ii} + M_j \Omega_{ji}$ and $M_j \Omega_{jj} + M_i \Omega_{ij}$ respectively. And they must also be equal to each other since the left hands sides of the two equations are the same. It follows that we must have $M_i \Omega_{ii}^* + M_j \Omega_{ji}^* = M_i \Omega_{ii}^* + M_j \Omega_{ji}^*$. Hence (10) and (11) immediately imply that $\Omega_{ii}^* > \Omega_{ij}^*$ for $i, j = H, F$. ■

7.3 Proof of Proposition 3

We first show part (ii). Adding up the first-order conditions for Ω_i and Ω_j under NT yields

$$2(C_c - C_m) - \pi = \frac{\gamma}{M_i \Omega_i + M_j \Omega_j} [(C_m - C_c)(M_i \Omega_i + M_j \Omega_j) + (M_i + M_j) C_c \overline{T}]. \quad \text{(A5)}$$

Comparing (A5) with either (A3) or (A4) and noting the monotonicity of the right-hand sides of these conditions regarding effective patent protection, we must have

$$P^{NT} = M_i\Omega_i^{NT} + M_j\Omega_j^{NT} = P^*,\ i,j = H,F$$

which establishes (ii).

Now notice that since $C_c - C_m - \pi < C_c - C_m - \mu_i\pi < C_c - C_m$, we must have $\frac{\gamma M_i}{P^*}[(C_m - C_c)\Omega_{ii}^* + C_c\overline{T}] < \frac{\gamma M_i}{P^{NT}}[(C_m - C_c)\Omega_i^{NT} + C_c\overline{T}] < \gamma\frac{M_i}{P^*}[(C_m - C_c)\Omega_{ij}^* + C_c\overline{T}]$ due to the first-order conditions for Ω_{ii}, Ω_i and Ω_{ij}. This implies

$$\Omega_{ii}^* > \Omega_i^{NT} > \Omega_{ij}^*,\ i,j = H,F$$

which is the desired result.

Finally, when countries are symmetric we may focus on the symmetric equilibria where $\Omega_{ii}^* = \Omega_{jj}^*$, $\Omega_{ij}^* = \Omega_{ji}^*$ under discrimination and $\Omega_i^{NT} = \Omega_j^{NT}$ under NT. Then (A3) and (A5) together imply that

$$\frac{1}{(\Omega_{ii}^* + \Omega_{ij}^*)}[(C_m - C_c)(\Omega_{ii}^* + \Omega_{ij}^*) + 2C_c\overline{T}] = \frac{1}{2\Omega_i^{NT}}[(C_m - C_c)2\Omega_i^{NT} + 2C_c\overline{T}],\ i,j = H,F.$$

Monotonicity of both sides ensures that we must have $\Omega_{ii}^* + \Omega_{ij}^* = 2\Omega_i^{NT}$. ■

7.4 Proof of Proposition 4

One can obtain the first-order conditions for country j by reversing i and j in (13) and (14). It is easy to show that

$$\Omega_{ii}^*(\theta) = \frac{C_c\overline{T}}{(2+\gamma)(C_c - C_m) - \pi}\left[(1+\gamma) - \frac{\eta\theta(C_c - C_m - \pi)}{(C_c - \theta C_m)}\right]$$

and

$$\Omega_{ij}^*(\theta) = \frac{C_c\overline{T}}{(2+\gamma)(C_c - C_m) - \pi}\left[\frac{(1+\gamma)(C_c - C_m) - \pi}{(C_c - \theta C_m)} - \frac{\eta}{\theta}\right]$$

where $\eta = M_j/M_i$. It follows that $\Omega_{ii}^*(\theta)$ decreases in θ since $\frac{\eta\theta(C_c - C_m - \pi)}{(C_c - yC_m)}$ is an increasing function of θ.

Similarly, $\Omega_{ij}^*(\theta)$ increases in θ since $\frac{(1+\gamma)(C_c - C_m) - \pi}{(C_c - \theta C_m)} - \frac{\eta}{\theta}$ is an increasing function of θ. Moreover, it can be shown that

$$P_i^*(\theta) = M_i\Omega_{ii}^*(\theta) + \theta M_j\Omega_{ji}^*(\theta) = \frac{\gamma C_c\overline{T}}{(2+\gamma)(C_c - C_m) - \pi}\left[M_i + M_j\frac{\theta(C_c - C_m)}{(C_c - \theta C_m)}\right].$$

Clearly, since $M_j\frac{\theta(C_c - C_m)}{(C_c - \theta C_m)}$ is an increasing function of θ, $P_i^*(\theta)$ is increasing in θ. ■

7.5 Proof of Proposition 5

We know that $\Omega^*(\theta)$ satisfies the following first-order condition:

$$2C_c-(1+\theta)C_m-\pi=\frac{\gamma}{(1+\theta)\Omega^*(\theta)}[(C_m-C_c)(1+\theta)\Omega^*(\theta)+(1+\theta)C_c\overline{T}-(1-\theta)\theta C_m\Omega^*(\theta)]. \tag{A6}$$

Similarly, $\Omega_d^*(\theta)$ and $\Omega_f^*(\theta)$ respectively satisfy the following first order conditions:

$$C_c-C_m-\pi=\frac{\gamma}{\Omega_d^*(\theta)+\theta\Omega_f^*(\theta)}[(C_m-C_c)\Omega_d^*(\theta)+C_c\overline{T}]$$

and

$$C_c-\theta C_m=\frac{\gamma\theta}{\Omega_d^*(\theta)+\theta\Omega_f^*(\theta)}[(\theta C_m-C_c)\Omega_f^*(\theta)+C_c\overline{T}].$$

Adding up the last two equations we obtain

$$\begin{aligned}2C_c-(1+\theta)C_m-\pi \;&=\; \frac{\gamma}{\Omega_d^*(\theta)+\theta\Omega_f^*(\theta)}[(C_m-C_c)(\Omega_d^*(\theta)+\theta\Omega_f^*(\theta))\\ &\quad +(1+\theta)C_c\overline{T}-(1-\theta)\theta C_m\Omega_f^*(\theta)].\end{aligned} \tag{A7}$$

Moreover, it can be shown that $\Omega^*(\theta)>\Omega_f^*(\theta)$, which further implies that $(1-\theta)\theta C_m\Omega^*(\theta)>(1-\theta)\theta C_m\Omega_f^*(\theta)$.[27] Since the right-hand sides of (A6) and (A7) must be equal, and since both are decreasing functions of $\Omega_d(\theta)+\theta\Omega_f(\theta)$ and $(1+\theta)\Omega(\theta)$, we may conclude that

$$\Omega_d^*(\theta)+\theta\Omega_f^*(\theta)>(1+\theta)\Omega^*(\theta).$$

Multiplying both sides by the common market size M, we get

$$M(\Omega_d^*(\theta)+\theta\Omega_f^*(\theta))>M(1+\theta)\Omega^*(\theta).$$

■

7.6 Proof of Proposition 6

Here, we show that it is socially optimal to discriminate even when $\Omega_{ii}=\overline{T}$.[28] Suppose $\Omega_{ii}=\overline{T}$ and $\Omega_{jj}<\overline{T}$. Here we must have $\Omega_{ji}\geq 0$ and $\Omega_{ij}=0$. It follows that country

[27] Note that $\Omega_d^*(\theta)>\Omega_f^*(\theta)$ in any interior equilibrium. Further, if $\Omega_f^*(\theta)\geq\Omega^*(\theta)$, then $\Omega_d^*(\theta)>\Omega_f^*(\theta)\geq\Omega^*(\theta)$ and this implies $\Omega_d^*(\theta)+\theta\Omega_f^*(\theta)>(1+\theta)\Omega^*(\theta)$. One can use the latter inequality to show that (A6) and (A7) cannot hold simultaneously. As a result, we must have $\Omega^*(\theta)>\Omega_f^*(\theta)$ in equilibrium.

[28] We rule out the uninteresting case where both countries are at a corner solution in terms of domestic protection where $\Omega_{ii}=\Omega_{jj}=\overline{T}$.

i discriminates (i.e. $\Omega_{ii} > \Omega_{ij}$). To show country j also discriminates (i.e. $\Omega_{jj} > \Omega_{ji}$), suppose $\Omega_{ji} > 0$ (otherwise we are done). Note that the social planner's FOC for Ω_{jj} is given by

$$C_c - C_m - \pi = \frac{\gamma}{P_j(\theta)}[(C_m - C_c)(M_j\Omega_{jj} + M_i\Omega_{ij}) + (M_i + M_j)C_C\overline{T} - (1-\theta)C_m M_j \Omega_{ij}]. \quad \text{(A8)}$$

Since $\Omega_{ij} = 0$, this simplifies (A8) as

$$C_c - C_m - \pi = \frac{\gamma}{M_j\Omega_{jj}}[(C_m - C_c)M_j\Omega_{jj} + (M_i + M_j)C_C\overline{T}]. \quad \text{(A9)}$$

Comparing (A9) with (21), we see that the left-hand side of (A9) is smaller than that of (21). This implies that the right-hand side of (A9) is also smaller than that of (21), i.e.

$$\begin{aligned} & \frac{\gamma}{P_i}[(C_m - C_c)(M_i\Omega_{ii} + M_j\Omega_{ji}) + (M_i + M_j)C_c\overline{T} - (1-\theta)C_m M_j\Omega_{ji}] \\ > \ & \frac{\gamma}{M_j\Omega_{jj}}[(C_m - C_c)M_j\Omega_{jj} + (M_i + M_j)C_C\overline{T}] \end{aligned} \quad \text{(A10)}$$

We next show that

$$P_i = M_i\Omega_{ii} + \theta M_j\Omega_{ji} \leq M_j\Omega_{jj} \quad \text{(A11)}$$

Suppose not, i.e., suppose we have

$$M_i\Omega_{ii} + \theta M_j\Omega_{ji} > M_j\Omega_{jj}$$

Since $\theta \leq 1$, we have

$$M_j\Omega_{jj} < M_i\Omega_{ii} + \theta M_j\Omega_{ji} \leq M_i\Omega_{ii} + M_j\Omega_{ji}$$

Then it follows that we must have

$$\begin{aligned} & \frac{\gamma}{M_j\Omega_{jj}}[(C_m - C_c)M_j\Omega_{jj} + (M_i + M_j)C_C\overline{T}] \\ > \ & \frac{\gamma}{P_i}[(C_m - C_c)(M_i\Omega_{ii} + M_j\Omega_{ji}) + (M_i + M_j)C_c\overline{T} - (1-\theta)C_m M_j\Omega_{ji}] \end{aligned}$$

which constitutes a contradiction of (A10). Therefore, it must be that

$$P_i = M_i\Omega_{ii} + \theta M_j\Omega_{ji} \leq M_j\Omega_{jj}.$$

Note that since Ω_{ji} is increasing in θ (so that it attains its maximum value at $\theta = 1$) while Ω_{jj} is independent of θ, if we can show that $\Omega_{jj} > \Omega_{ji}$ at $\theta = 1$ then it must be this inequality holds for all θ. When $\theta = 1$, (A11) binds so that $M_i\Omega_{ii} + M_j\Omega_{ji} = M_j\Omega_{jj}$. This immediately implies $M_j\Omega_{ji} < M_j\Omega_{jj}$ from which it follows that $\Omega_{ji} < \Omega_{jj}$, i.e. given that country i is discriminating, it is socially optimal to have country j discriminate under free trade. Moreover, Ω_{ji} falls while Ω_{jj} does not change as θ decreases, so $\Omega_{ji} < \Omega_{jj}$ continues to hold when $\theta < 1$. ■

7.7 Multiple countries

For simplicity, our core model considers a two-country setting. We now show that the key driving forces behind our analysis carry over to a multi-country scenario. To shed light on the key mechanisms that operate in a multi-country setting, in the following analysis we assume that all countries are symmetric so that $\Omega_{ii} = \Omega_{jj} = \Omega_d$ and $\Omega_{ij} = \Omega_{ji} = \Omega_f$.

Consider a world composed of n symmetric countries with θ measuring the degree of trade openness between any two of them. Under discrimination we can write the equilibrium effective global patent protection received by a typical country as

$$P^*(\theta, n) = M[\Omega_d + \theta(n-1)\Omega_f]$$

Similarly, under NT the effective protection given to a country is

$$P^{NT}(\theta, n) = M\Omega[1 + \theta(n-1)]$$

Thus both $P^*(\theta, n)$ and $P^{NT}(\theta, n)$ are straightforward generalizations of the two-country case.

Under discrimination $P^*(\theta, n)$ satisfies the following FOCs for country i:

$$C_c - C_m - \pi = \frac{\gamma M}{P^*(\theta, n)}[(C_m - C_c)\Omega_d + C_c\overline{T}], \tag{A12}$$

and

$$C_c - \theta C_m = \frac{\gamma\theta M}{P^*(\theta, n)}[(\theta C_m - C_c)\Omega_f + C_c\overline{T}] \quad \text{for } j \neq i \tag{A13}$$

where (A12) is for domestic protection and (A13) is for the patent protection provided by country i to country j.

On the other hand, under NT each country simply chooses a uniform patent protection and the FOC for country i can be written as

$$\begin{aligned} C_c - \left[\frac{1+(n-1)\theta}{n}\right] C_m - \frac{\pi}{n} \quad = \quad & \frac{\gamma M}{nP^{NT}(\theta, n)}[(C_m - C_c)\Omega + C_c\overline{T}] \\ & + \frac{(n-1)\gamma\theta M}{nP^{NT}(\theta, n)}[(\theta C_m - C_c)\Omega + C_c\overline{T}]. \end{aligned} \tag{A14}$$

Adding up the FOCs over all countries we obtain the following key equation in a symmetric equilibrium under discrimination:

$$nC_c - [1+(n-1)\theta]C_m - \pi = \frac{\gamma}{P^*}[(C_m - C_c)P^* + [1+(n-1)\theta]C_c\overline{T} - (n-1)(1-\theta)\theta C_m\Omega_f(\theta)] \tag{A15}$$

Similarly, under NT we can write

$$nC_c-[1+(n-1)\theta]C_m-\pi = \frac{\gamma}{P^{NT}}[(C_m-C_c)P^{NT}+[1+(n-1)\theta]C_c\overline{T}-(n-1)(1-\theta)\theta C_m\Omega^*(\theta)]. \tag{A16}$$

Since the left hand side of the two equations above are the same while $\Omega^*(\theta) > \Omega_f^*(\theta)$ (i.e. NT protection is greater than foreign protection under discrimination) it must be that, in equilibrium, we have $P^* > P^{NT}$ for every country. Therefore, in a n-country (symmetric) world, total patent protection and therefore innovation and aggregate welfare are higher under discrimination relative to NT.[29] The key mechanism is analogous as in the benchmark case: NT requires all countries to overuse foreign protection that, in the presence of trade frictions, is less effective than domestic protection for incentivizing innovation.

Consider now the perspective of the social planner. We have

$$\begin{aligned}\frac{\partial WW^D(\theta)}{\partial \Omega_d} &= \frac{\phi M}{\rho}[\frac{\gamma}{P}[(C_m - C_c)(M\Omega_d + (n-1)M\Omega_f) + nMC_c\overline{T} \\ &\quad -(1-\theta)(n-1)C_m M\Omega_f] - (C_c - C_m - \pi)]. \end{aligned} \tag{A17}$$

Similarly, we have

$$\begin{aligned}\frac{1}{\theta}\frac{\partial WW^D(\theta)}{\partial \Omega_f} &= \frac{\phi M}{\rho}[\frac{\gamma}{P}[(C_m - C_c)(M\Omega_d + (n-1)M\Omega_f) + nMC_c\overline{T} \\ &\quad -(1-\theta)(n-1)C_m M\Omega_f] - (C_c - C_m - \pi) - \frac{(1-\theta)}{\theta}C_c]. \end{aligned} \tag{A18}$$

From these two first equations it follows that

$$\frac{\partial WW^D(\theta)}{\partial \Omega_d} - \frac{1}{\theta}\frac{\partial WW^D(\theta)}{\partial \Omega_f} = \frac{\phi M(1-\theta)C_c}{\rho\theta} > 0,$$

where $M_i = M$ for $i \in 1, 2, ..., n$. Hence, the net social marginal benefit of domestic protection is higher than that of foreign protection even when there are more than two countries in the world.

[29] We also conduct numerical anslysis for a 3-country asymmetric world. All the qualitative results under the 2-country world continue to hold.

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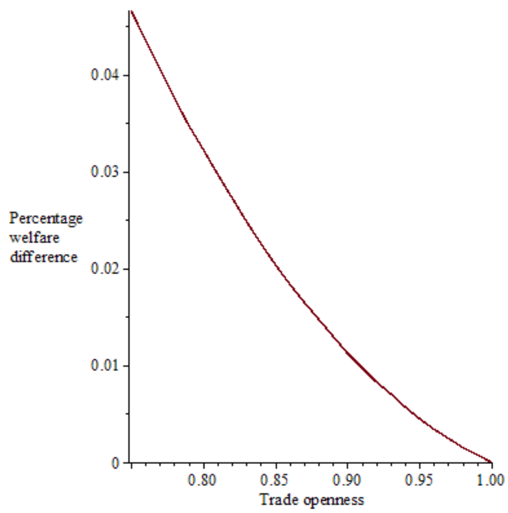

Figure 1: Discrimination versus NT: how trade openness matters

Table1: Equilibrium patent protection and welfare in a North-South world

θ	$\Omega_i^{NT}/\Omega_{ii}^*$	$\Omega_i^{NT}/\Omega_{ij}^*$	$\Omega_j^{NT}/\Omega_{jj}^*$	$\Omega_j^{NT}/\Omega_{ji}^*$	P_i^{NT}/P_i^D	P_j^{NT}/P_j^D	W_i^{NT}/W_i^D	W_j^{NT}/W_j^D
0.8	0.948	1.186	0.593	1.544	1.011	0.964	0.980	0.959
0.9	0.955	1.122	0.699	1.280	1.005	0.986	0.993	0.984
1.0	0.967	1.073	0.807	1.135	1.000	1.000	1.000	1.000

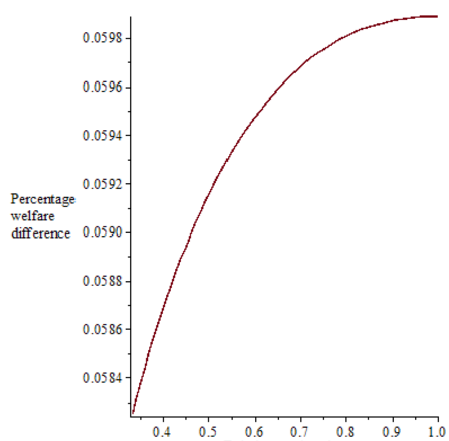

Figure 2: Comparison when market size differs across countries

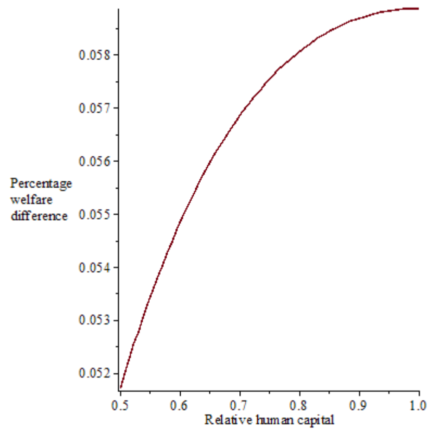

Figure 3: Welfare difference with asymmetric human capital stocks

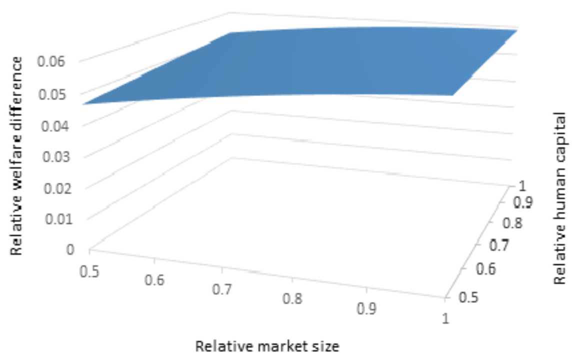

Figure 4: Welfare difference with asymmetric market sizes and human capital stocks