Tariff barriers and the protection of intellectual property in the global economy

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Abstract

This paper develops a simple two-country model of quality-improving innovation to study the role tariff barriers play in shaping the welfare impact of global patent protection. We show that international patent policy coordination via national treatment is desirable only if tariff barriers between countries are sufficiently low. Furthermore, if countries are free to impose their optimal tariffs on one another, requiring national treatment in patent protection unambiguously lowers world welfare. Hence, constraining tariffs helps pave the way for international coordination over patent protection. This insight provides a potential rationale for the historical sequencing of policy reforms observed in the global trading system: multilateral rules on intellectual property were adopted only after decades of trade negotiations had succeeded in substantially reducing global tariffs.

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1 Introduction

During the past seventy years or so, the multilateral trading system has been remarkably successful in reducing traditional policy barriers to international trade. From 1947-95, eight rounds of multilateral trade negotiations were conducted under the auspices of the General Agreement on Tariffs and Trade (GATT), a multilateral treaty focused on international trade in goods. These eight GATT rounds delivered substantial multilateral trade liberalization, eventually reducing the average ad-valorem tariff on industrial goods to under four percent (Bagwell, Bown, and Staiger, 2016). The last major GATT round – i.e. the Uruguay round – led to the formation of the World Trade Organization (WTO) in 1995, an organization that today includes not just GATT but also the Agreement on Trade Related Aspects of Intellectual Property (TRIPS) – the key multilateral treaty that now governs rules and regulations pertaining to the protection of intellectual property in the global economy. The inclusion of TRIPS in the WTO raises a key question: what role do tariff barriers play in determining the welfare impact of national patent policies?[1] We address this question by focusing on a core TRIPS obligation, i.e., the *national treatment* clause which calls for WTO member countries to offer foreign firms the same level of patent protection that they provide their domestic firms.[2] We show that trade liberalization is a *prerequisite* for national treatment in patent protection to be welfare-improving. This result suggests that the liberalization of trade in goods that occurred under the GATT/WTO system eventually helped pave the way for TRIPS by making its welfare impact relatively more palatable.

To address the key issues motivating the paper, we build a tractable two-country model of trade and innovation. Each country has one firm that sells its product in both markets. For simplicity, the products of the two firms are assumed to be unrelated to each other (i.e. each firm is a monopolist in its own product market). Prior to production and sales, firms invest in R&D which determines the quality of their respective products. Countries have multiple policy instruments at their disposal that affect innovation and trade. First, each country chooses whether or not to offer patent protection to firms. If a firm receives patent protection in a market, it enjoys monopoly status there. When such protection is absent, it faces competition from the imitated product. Second, each

[1]Existing literature has argued persuasively that IPRs are *trade-related*, i.e., the IPR policies of trading countries affect the pattern and volume of trade – see, for example, Maskus and Penubarti (1995) and Ivus (2010, 2015). But the welfare question we address here has not received much attention in this literature – see Saggi (2016) for a survey.

[2]To be sure, the notion of national treatment did not originate with TRIPS. Indeed, national treatment is specified as an obligation even under the Paris Convention of 1883. But TRIPS obligations are backed by the WTO's potent dispute settlement process that allows an aggrieved country to file a case with the WTO (and potentially retaliate) in case the IPRs of its nationals have been violated by another member country. Access to the WTO's dispute settlement procedures gives TRIPS a level of bite that earlier IPR treaties such as the Paris Convention lacked.

country chooses its ad-valorem import tariff. Finally, we consider a scenario where countries can also utilize R&D subsidies to incentivize innovation.

Our benchmark model focuses on the interaction between import tariffs and patent protection in a symmetric setting. We show that the lower the import tariff of a country, the less likely is the *other* country to grant patent protection to its own firm since greater profitability abroad makes domestic patent protection less crucial for incentivizing innovation. Interestingly, it turns out that there is a non-monotonic relationship between a country's import tariff and the impact that granting patent protection to the foreign firm has on its welfare (which is *negative* if the foreign firm receives patent protection from its own government). Specifically, a reduction in a country's tariff has two opposing effects on its incentive for granting patent protection to the foreign firm. First, a reduction in a country's import tariff makes its patent protection more effective in incentivizing the foreign firm's R&D by increasing its product market profits (a *complementary effect*). Second, a reduction in a country's import tariff makes its patent protection towards the foreign firm less salient for incentivizing R&D on its part (i.e. the tariff reduction partly *substitutes* for foreign patent protection). It turns out that the complementary effect dominates when the initial tariff is high whereas the opposite holds when the initial tariff level is low. This finding suggests that there may be diminishing returns in the innovation dividends that can be expected from trade liberalization: i.e. all else equal, the innovation incentive effects of reducing tariff barriers in countries where such barriers are still relatively high (such as Egypt or India) are likely to exceed those that can be obtained from further liberalizing trade in economies that are already quite open (such as the United States or Germany).

Holding tariffs constant, we find that national patent protection levels are *substitutes across countries*. In particular, a country is *less likely* to protect a firm (regardless of whether it is domestic or foreign) if that firm receives patent protection from the other country. An important implication of this finding is that countries have incentives to free ride on each other, so that the Nash equilibrium features insufficient patent protection. Such strategic substitutability and the under-provision of patent protection also arise in trade models of variety-expanding R&D (Grossman and Lai, 2004; Geng and Saggi, 2015). The present paper complements this literature by revealing that strategic incentives underlying national patent policies do not depend on the nature of innovation being considered.

An important result of this paper is that, in Nash equilibrium, each country grants patent protection to its own firm while denying such protection to the foreign firm. Such a pattern of discriminatory equilibrium patent policies is consistent with anecdotal evidence as well as the formal empirical literature on the subject – i.e. countries indeed tend to discriminate against foreign firms in the enforcement of intellectual property rights (IPRs).[3] In our model, countries discriminate against foreign firms primarily due to profit considerations: when a country grants patent protection to a foreign firm, the resulting increase in firm's monopoly profits accrues entirely to the foreign country and therefore does not contribute to its welfare.

A natural question that follows is whether the lack of patent protection for foreign firms can ever be justified on welfare grounds. To answer this question, we examine international patent coordination that requires each country to follow national treatment by extending patent protection to each other's firms. One practical example of such type of coordination is the Patent Cooperation Treaty (PCT) which allows innovators to file patent applications simultaneously in multiple countries that are signatories of the treaty. As de Rassenfosse et al. (2019) show, the PCT helps reduce discrimination in national patent policies by making them better aligned with national treatment. We show that the impact of such patent coordination depends critically on the level of tariffs imposed by countries. In particular, requiring a country to follow national treatment in patent protection lowers world welfare when its tariff is high whereas it raises welfare when it is low. The intuition for this unexpected finding is as follows. When a country's import tariff is high, its patent policy towards the foreign firm does not play a major role in determining the firm's R&D incentive since its export profits are small and this, in turn, weakens the rationale for protecting the foreign firm. In the limit, when a country's tariff is almost prohibitive, it has virtually nothing to gain from protecting the foreign firm since doing so simply eliminates the imitated version of the product from the local market without providing *any* offsetting benefit to local consumers.[4] This result shows that the degree of trade liberalization in the global economy is a major determinant of the desirability of providing stronger patent protection to foreign innovators.

Do these results hold when tariffs are endogenously determined? To address this question, we derive equilibrium patent policies when countries impose nationally optimal tariffs on one another. The key conclusion is that allowing for endogenous tariffs does not affect the incentives that countries have to deny patent protection to foreign firms. More importantly, in the presence of nationally optimal tariffs, requiring countries to follow national treatment in patent protection necessarily *lowers* world welfare. When tariffs are endogenous, strengthening patent protection towards the foreign firm induces a

[3]For empirical studies examining the actual implementation of national treatment in patent policy see Kotabe (1992), Liegsalz and Wagner (2013), Azagra-Caro and Tur (2014), Webster et al. (2014), de Rassenfosse and Raiteri (2016), de Rassenfosse et al. (2019). and Mai and Stoyanov (2019).

[4]This result fits well with the argument that stronger patent protection in developing countries will fail to raise local and global welfare if patent-holders simply choose to stay out of their markets despite such protection because they either do not find market conditions to be particularly attractive (Bond and Saggi, 2018) or are concerned about international price spillovers arising from parallel trade and/or the presence of external reference pricing policies that undercut their profits in larger markets.

country to raise its import tariff. The intuition for this result is that when the foreign firm is freed from imitative competition, its profit margin increases which, in turn, increases the importing country's incentive to extract rent from it. The tariff increase that results from the strengthening of patent protection granted to the foreign firm dampens its innovation incentive and therefore reduces welfare. Interestingly, these findings echo the widely held concern that stronger patent protection in the global economy could lower welfare (see, for example, Boldrin and Levine, 2013). Our analysis identifies a plausible scenario where this concern is borne out: i.e. extending patent protection to foreign firms when import tariffs are completely unconstrained is unambiguously welfare-reducing.

We also investigate how trade policy coordination affects the efficiency implications of national treatment in patent protection. First, since tariffs are efficiency reducing in our model, countries choose to eliminate tariffs if trade policies are chosen to maximize joint welfare. The move to national treatment in patent protection in the presence of trade coordination is socially desirable in our model since strengthening foreign patent protection under free trade necessarily raises world welfare. Hence, trade policy coordination is sufficient for countries to benefit from instituting national treatment in international patent protection. An important policy implication of this result is that trade policy coordination produces not only direct welfare gains through liberalizing trade but also indirect gains by facilitating coordination over behind-the-border policy instruments such as patent protection.

Finally, we consider two important extensions of the benchmark model. First, we examine the implications of market asymmetry across countries so as to capture a key difference between developed and developing countries. While our main conclusions remain qualitatively unchanged, we show that the under-protection of patents tends to be more severe in countries with smaller markets. As a consequence, patent coordination between asymmetric countries may need to focus on the tightening of patent standards in smaller or less developed countries, a finding consistent with the provisions of many real-world trade agreements, both preferential trade agreements such as the North American Free Trade Agreement (NAFTA) and multilateral agreements such as TRIPS. Our analysis also yields an interesting auxiliary result: countries with larger markets tend to impose lower tariffs because they benefit more from foreign R&D. This finding is in line with the evidence found in Naito (2019), and it provides a novel insight: i.e. the observed negative correlation between market size and tariff rates may partly be driven by innovation considerations.

In our second extension, we allow countries to subsidize R&D. This is an empirically relevant case as R&D subsidies are widely used and are indeed permitted by the WTO. In addition, it is well-known that patent protection is not necessarily the most effective means for incentivizing innovation as it increases monopoly power and can also give rise to various other problems that tend to reduce efficiency (Boldrin and Levine, 2013). We show that, as expected, R&D subsidies are more efficient in promoting innovation than patent protection. As a result, coordination over R&D subsidies can lead to a superior welfare outcome than international patent coordination. This insight offers a potential explanation for why R&D subsidies are not banned under the WTO and also suggests that there might be a fruitful role for international coordination over such subsidies.

To the best of our knowledge, only two other theoretical papers examine the interaction between tariff and patent policies.[5] The first is Geng and Saggi (2015) who also analyze the impact of tariff reductions on global patent protection. However, there are important differences between that paper and the present one. First, the two papers examine innovations of different nature: innovation expands varieties in Geng and Saggi (2015) but improves quality in the present model. Second and perhaps more importantly, Geng and Saggi (2015) assume tariff barriers to be exogenous so that their analysis cannot answer the central question addressed in our paper, which is the welfare impact of requiring national treatment in patent policy when countries are free to set their optimal tariffs on one another.

Mandelman and Waddle (2020) also identify linkages between one country's tariff policy and its trading partner's patent policy. Their analysis differs from ours in several aspects. First, Mandelman and Waddle assume both tariffs and patent protection as exogenous policy variables whereas we endogenize both. Second, they do not consider policy coordination - a central focus of this paper. Third, Mandelman and Waddle consider a macro type model of monopolistic competition which allows them to study transitional dynamics of policy changes. By contrast, we develop a micro model of vertical quality differentiation and focus on its comparative statics.

Finally, our paper also relates to a small number of theoretical studies on the linkages between tariffs and national treatment in internal measures other than patent protection. Some of these studies examine corporate taxes (Horn, 2006) while others look at product standards (Geng, 2021). A common insight yielded by this literature is that tariff liberalization is conducive to the welfare impact of requiring national treatment in internal measures.[6]

The paper proceeds as follows. In Section 2 we develop the benchmark model. Section

[5] There also exists a theoretical literature that examines strategic patent policy in an open economy (Lai and Qiu, 2003; Grossman and Lai, 2004; Lai and Yan, 2013). However, all these papers assume free trade (i.e. do not consider tariff policies).

[6] Our paper also relates to a burgeoning literature on the economics of deep integration which focuses on coordination over behind-the-border measures (for example Bagwell and Staiger, 2001; Ederington, 2001; Grossman et al., 2021). See Maggi and Ossa (2020) for a recent review of this literature.

3 uses this model to analyze the interaction between national trade and patent policies. Section 4 considers various extensions of the benchmark model and Section 5 concludes.

2 Model

Consider a world economy comprising two countries: i and j. A single firm in each country produces a distinct good. Consumers in both countries consume both goods so that country i exports good i to country j while importing good j from it. Each consumer buys at most one unit of each good. If a consumer buys one unit of good k where $k = i$ or j, her utility is given by $u_k = q_k\theta - p_k$, where q_k measures the quality of good k and θ measures the consumer's taste for quality. Utility under no purchase is normalized to zero. For simplicity, we assume that θ is uniformly distributed over the interval $[0, m_k]$ in country k where $m_k \geq 1$. It follows that the average willingness of consumers to pay for quality in country k is $m_k/2$.[7] The total utility of a consumer in country k is additively separable over the two goods such that $u_k = u_{ki} + u_{kj}$. The number of consumers in country k is given by $n_k > 0$. Let $\mu_k = m_k n_k$ measure the effective size of country k's market demand.

The quality of good k is endogenously determined by firm k's R&D investment. Let the R&D cost function for firm k be given by $C_k(q_k) = \delta_k q_k^2/2$ where $\delta_k > 0$ measures the firm's R&D productivity. Each country may choose to grant a R&D subsidy to its firm which is denoted with $s_k \geq 0$. To facilitate exposition, we initially assume $s_k = 0$ and discuss the case where $s_k > 0$ in Section 4.2. The marginal cost of production of each firm is normalized to zero.[8] Markets are segmented so that firms can freely set market-specific prices to maximize their global profits.

Government in each country imposes an ad-valorem import tariff on the foreign firm.

[7] Without loss of generality, we have implicitly assumed that the distributions of θ for the two goods are identical within each country, although they can be different across countries when $m_i \neq m_j$. Such heterogeneity in preferences for quality across countries is commonly observed in the sense that consumers in rich countries tend to have a higher willingness to pay for quality than that those in poor countries.

[8] For simplicity, we abstract from global supply chains which involve production and trade of intermediate goods. Doing so allows us to tractably characterize the inter-relationship between incentives for patent protection and tariff barriers. The role of intermediate goods trade has drawn increasing attention from recent studies (Buera et al., 2020; Cai et al., 2020; Mandelman and Waddle, 2020). One important effect of intermediate goods trade is that it may facilitate technology diffusion from multinational parents to their foreign subsidiaries. This channel is not present in our model as we focus on imitation of the final good in the absence of patent protection as the sole channel of technology diffusion. If the good subject to imitation/diffusion were an intermediate good then patent protection or the lack of it would impact producers at multiple stages. Incorporating such vertical linkages into the analysis of tariff and patent policies is an important direction for future research.

Let τ_k denote country k's import tariff on firm $\widetilde{k}$, where $0 \leq \tau_k < 1$ and $\widetilde{k}$ stands for not k. Each country also needs to choose its patent policies towards the domestic and the foreign firms. Let $\mathbf{\Omega}_k = \{\Omega_{kk}, \Omega_{k\widetilde{k}}\}$ be country k's patent policy profile where Ω_{kk} and $\Omega_{k\widetilde{k}}$ represent its patent protection for the domestic and the foreign firm. In our simple formulation, the variable Ω either equals P (protection) or I (no protection). In particular, when a firm is granted patent protection by country k, it acts as a monopoly in the country's market.

If a firm receives no patent protection in a country, its technology is imitated locally and imitation leads to the emergence of a competitive industry that produces a lower quality version of the firm's product. Let $\gamma_{kk}q_k$ and $\gamma_{k\widetilde{k}}q_{\widetilde{k}}$ denote the quality of country k's imitation of the domestic and the foreign good, with γ_{kk} and $\gamma_{k\widetilde{k}} \in [0, 1)$ representing country k's imitation capacity for the two goods respectively.[9] We allow $\gamma_{kk} \neq \gamma_{k\widetilde{k}}$ so that a country's imitation capacity can be different for domestic and foreign goods. This is true, for example, when it is more difficult to imitate the foreign good due to factors such as information frictions, in which case we have $\gamma_{k\widetilde{k}} < \gamma_{kk}$. Observe that when a country is incapable of imitating a firm's product (i.e. γ_{kk} or $\gamma_{k\widetilde{k}}$ equals 0), its patent policy towards the firm becomes irrelevant. Finally, all imitated products are assumed to be sold locally.[10]

The timing of decision making is as follows. In the first stage, countries choose their respective patent and tariff policies (and possibly R&D subsidies). Then, given the policies set by countries, each firm chooses its investment in R&D that determines the quality of its product. Finally, international trade and consumption take place. We use backward induction to solve this game.

Before proceeding with formal analysis, it is useful to highlight the empirical relevance of our modeling approach. The central real-world motivation behind our model's key features is the structure of the pharmaceutical industry and its reliance on patent protection. First, as is well known, the R&D/sales ratios in the pharmaceutical industry is much higher (almost 5 times as much) as that for the manufacturing sector at large (Scherer, 2010). Second, patent protection plays an outsized, almost unique role in the pharmaceutical industry. A dated but influential survey by Levin et al. (1987) of 650 corporate R&D managers found that patents were perceived to be a highly effective

[9]Modeling patent protection as a binary decision variable is without loss of generality. The key insights yielded by our analysis carry over when patent protection is continuous, e.g. when countries can choose the degree of imitation (γ_i) facing firms.

[10]This could be due to countries enforcing different patent policies. For example, an imitated product in one country may not be allowed for sale in another if the latter's patent protection for the product remains effective. Moreover, even when patent protection for a product is globally absent, an imitated product may only be sold locally if quality standards for it differ across countries. See Geng and Saggi (2019) for a discussion of trade of generic drugs as an example of this scenario.

means for encouraging innovation in the pharmaceutical industry.[11] Third, and somewhat crucially so, not only are substantive R&D investments required for successful drug discovery, the costs of imitating successful drugs are rather small, sometimes trivially so. By contrast, for example, while the aircraft industry also has to invest large amounts in R&D to come up with successful innovations (such as a new commercial jet engine or plane), the costs of imitating a commercially successful product in this industry are roughly the same order of magnitude as inventing a new one. It seems clear then that patents are most effective for incentivizing innovation when high costs of innovation co-exist with low costs of imitation, as they do in the pharmaceutical industry. This juxtaposition of high innovation costs on the one hand and low imitation costs on the other is captured sharply in our model by assuming costly R&D and essentially free imitation (provided local patent protection policy permits it).

The ease with which pharmaceuticals can be imitated together with the existence of weak IPR regimes is primarily what allowed several major developing countries (such as India and Brazil) to develop significant pharmaceutical industries of their own. For example, prior to 2005, India did not even recognize product patents for pharmaceuticals; only process patents were protected. This meant that if a local Indian firm could reverse-engineer a patented foreign pharmaceutical product (i.e. make it with its own process), it was free to produce and sell the drug locally as well in any other country that followed a similar patent regime. This patent policy created conditions suitable for the development of a robust pharmaceutical industry in India that has now become a key producer of generics for the global market, and is often referred to as the "pharmacy of the world".[12] Watal (2001) provides a fascinating account of the role that the US pharmaceutical industry played in pushing for IPR reforms in countries such as Brazil and India and how the industry's proposals helped shape the eventual form and content of the TRIPS agreement. She also notes how developing countries were successful in pushing for incorporating compulsory licensing into TRIPS in situations where a country had a national emergency or could not gain access to key patented pharmaceuticals. This latter point dovetails nicely with our central argument: if patent protection does not improve access in developing countries to patented pharmaceuticals because trade barriers are high, it is difficult to see how the TRIPS-mandated strengthening of patent

[11] Related findings were reported by Mansfield (1986) wherein R&D executives of pharmaceutical firms reported that almost 60% of their commercialized innovations between 1981-83 would not have been developed in the absence of patent protection.

[12] It is worth noting that this technological capacity has been crucial for making it possible for India to produce the Oxford/AstraZeneca COVID-19 vaccine at a large scale. If this had not been possible, much of India's population may have had very limited access to a protective vaccine. Although India's pharmaceutical industry has not yet become a true global innovator, it might cross this threshold one day in part due to cumulative learning by doing and the extensive international collaboration that is occurring in this industry today.

protection in developing countries under such conditions could be welfare-improving.

2.1 Pricing and trade

We begin by analyzing the final stage of the game where firms choose their prices across markets to maximize their global profits, treating as given the quality levels of their products as well as government's patent and trade policies. Without loss of generality, let us focus on firm i's profit maximization problem as firm j's problem can be formulated and solved analogously. Given tariff τ_j, firm i chooses its market-specific prices to maximize the sum of its profit in each market

$$\max_{p_{ii},\, p_{ij}} \pi_{ii}^{R}(p_{ii}) + (1-\tau_j)\pi_{ij}^{R}(p_{ij}) \tag{1}$$

where the superscript $R = P$ or I denotes whether the firm receives patent protection from a country or not. Since markets are segmented, the firm's problem is the same as separately maximizing its profit in each market

$$\max_{p_{ii}} \pi_{ii}^{R}(p_{ii}) \text{ and } \max_{p_{ij}} \ (1-\tau_j)\pi_{ij}^{R}(p_{ij}) \tag{2}$$

Note that firm i's profit in country k depends upon the patent policy of only that country. When receiving patent protection in country k, firm i becomes the monopoly seller of the good in the country. It is easy to show that given the firm's price p_{ik}, country k's consumers are partitioned into two groups: those in the range $[p_{ik}/q_i, m_k]$ buy good i and those in $[0, p_{ik}/q_i]$ do not buy. Thus firm i's pre-tariff profit earned in country k is given by

$$\pi_{ik}^{P}(p_{ik}) = \frac{n_k}{m_k} p_{ik}(m_k - \frac{p_{ik}}{q_i}) \quad \text{for } k = i, j \tag{3}$$

It can be shown that firm i's optimal price in country k is $p_{ik}^{*}(q_i) = m_k q_i/2$. The associated sales and profits equal $x_{ik}^{*} = n_k/2$ and $\pi_{ik}^{*} = \mu_k q_i/4$ respectively.

When firm i does not receive patent protection in country k, competition within the imitative industry ensures that the imitated good (of lower quality) is sold in the local market at marginal cost. When two different qualities are available for purchase in country k at prices p_{ik} (high quality) and 0 (low quality), consumers can be partitioned into two groups: those in the range $[0, p_{ik}/q_i(1-\gamma_{ki})]$ buy the low quality whereas those in $[p_{ik}/q_i(1-\gamma_{ki}), m_k]$ buy the high quality. Hence firm i's pre-tariff profit in country k is

$$\pi_{ik}^{I}(p_{ik}; \gamma_{ki}) = \frac{n_k}{m_k} p_{ik}[m_k - \frac{p_{ik}}{q_i(1-\gamma_{ki})}] \quad \text{for } k = i, j \tag{4}$$

It follows that the firm's optimal price when facing competition from the imitative industry equals $\widehat{p}_{ik} = m_k q_i(1-\gamma_{ki})/2$. Observe that $\widehat{p}_{ik} = (1-\gamma_{ki})p_{ij}^{*}$ so that $\widehat{p}_{ik} \leq p_{ik}^{*}$ for

$\gamma_{ki} \in [0, 1)$. This indicates that each firm charges a lower price when facing competition from imitation. Finally, it is easily shown that firm i's maximized profits under imitation satisfy the following conditions

$$\widehat{\pi}_{ik} = (1 - \gamma_{ki})\pi^*_{ik} \quad \text{for } k = i, j \tag{5}$$

which implies that $\widehat{\pi}_{ik} \leq \pi^*_{ik}$, i.e., imitation lowers the firm's profits.

2.2 R&D

Next consider the second stage of the game where firms decide on their R&D investments. Each firm's R&D incentives depend on its expected global profit which further hinges on the patent protections it receives in the two countries. When given no patent protection in either country, firm i's optimal R&D investment solves

$$\max_{q_i} \; \pi^I_{ii}(q_i) + (1 - \tau_j)\pi^I_{ij}(q_i) - C_i(q_i) \tag{6}$$

Let the solution to this problem be denoted by q^I_i. It is easy to show that

$$q^I_i(\gamma_{ii}, \gamma_{ji}) = \frac{(1 - \gamma_{ii})\mu_i + (1 - \tau_j)(1 - \gamma_{ji})\mu_j}{4\delta_i}. \tag{7}$$

Observe that q^I_i is decreasing in γ_{ki} and τ_j but increasing in μ_k. Intuitively, competition from either imitation (e.g. higher γ_{ki}) or foreign tariff (e.g. higher τ_j) dampens firm i's R&D incentives by reducing its expected global profit, whereas greater market demand (e.g. higher μ_k) raises the firm's profits and thus its R&D incentives.[13] Hence we can state the following:

Lemma 1. *(i) A firm's R&D investment is decreasing in the intensity of competition it faces from the imitated product in either country (i.e. $\partial q^I_k/\partial \gamma_{lk} < 0$ for $k, l = i, j$) as well as in the degree of foreign tariff barriers (i.e. $\partial q^I_k/\partial \tau_{\widetilde{k}} < 0$ for $k = i, j$).*

(ii) A firm's R&D investment increases with market demand in either country (i.e. $\partial q^I_k/\partial \mu_l > 0$ for $k, l = i, j$).

We use q^{Ik}_i to denote firm i's optimal R&D investment when it faces imitation in country k only. In particular, $q^{Ik}_i = q^I_i(\gamma_{\widetilde{k}i} = 0)$. Also, let q^*_i be firm i's R&D investment when receiving patent protection in both countries so that $q^*_i = q^I_i(\gamma_{ii} = 0, \gamma_{ji} = 0)$.

[13] Our model abstracts from heterogeneity in imitation quality or R&D effectiveness across industries. While a complete analysis of this issue is beyond the scope of this paper, our model does yield some relevant insights. For example, it can be shown that the welfare gains from national treatment under free trade increase with the quality of imitation (γ). This suggests that the case for national treatment may be stronger in industries where imitation poses a greater threat for innovation incentives (e.g. the pharmaceutical industry). The bottom line is that the a one-size-fits-all patent policy that is prevalent today is unlikely to be economically optimal even though it maybe administratively efficient.

2.3 Welfare

When firm k does not receive patent protection either country, aggregate consumer surplus in country i over good k can be calculated as

$$cs_{ik}(\gamma_{ik},\gamma_{jk}) = \frac{n_i}{m_i} \int_0^{p_{ki}/q_k^I(\gamma_{ik},\gamma_{jk})(1-\gamma_{ik})} \gamma_i q_k^I(\gamma_{ik},\gamma_{jk})\theta d\theta \tag{8}$$
$$+ \frac{n_i}{m_i} \int_{p_{ki}/q_k^I(\gamma_{ik},\gamma_{jk})(1-\gamma_{ik})}^{m_i} \left[q_k^I(\gamma_{ik},\gamma_{jk})\theta - p_{ki}\right] d\theta \quad \text{for } k = i, j$$

where the first and the second terms represent the welfare of consumers who buy the imitated and the original good respectively. Note that $cs_{ik}(\gamma_{ik},\gamma_{jk})$ also depends on the patent protection firm k receives in country j since it affects the firm's choice of quality q_k^I. When country i extends patent protection to firm k, its consumer surplus over good k is $cs_{ik}|_{\gamma_{ik}=0}$. Similarly, when both countries protect firm k, country i's consumer surplus over good k becomes $cs_{ik}|_{\gamma_{ik}=\gamma_{jk}=0}$.

Country i's national welfare is defined as the sum of its consumer surplus over the two goods, its firm's global profit and its tariff revenue

$$w_i = \sum_k cs_{ik} + \pi_i + TR_i \quad \text{for } k = i, j \tag{9}$$

It is useful to write w_i as

$$w_i = w_{ii} + w_{ij} \tag{10}$$

where w_{ii} and w_{ij} are country i's welfare derived from good i and j respectively, where

$$w_{ii} = cs_{ii} + \pi_i \text{ and } w_{ij} = cs_{ij} + TR_i \tag{11}$$

with $TR_i = \tau_i \pi_{ji}$ being country i's tariff revenue collected from firm j. The expression of w_{ii} indicates that country i's welfare over good i arises from two sources: its consumer surplus derived from good i and firm i's global profit. Similarly, country i's welfare over good j has two components: its consumer surplus derived from good j and the tariff revenue it collects from firm j.

Let world welfare be the sum of each country's national welfare

$$WW = w_i + w_j. \tag{12}$$

Note that world welfare can also be decomposed as

$$WW = WW_i + WW_j \tag{13}$$

where WW_i and WW_j represent the components of world welfare associated with good i and j respectively, where

$$WW_i = w_{ii} + w_{ji} \text{ and } WW_j = w_{ij} + w_{jj}. \tag{14}$$

Notably, since there is no strategic interaction between firms, WW_k depends on the quality of good k but not that of good $\widetilde{k}$. An important consequence is that WW_i and WW_j are independent of each other in the sense that they are determined by two independent sets of policy instruments. In particular, WW_k is affected by each country's patent protection toward firm k (Ω_{ik} and Ω_{jk}) as well as the tariff firm k faces when exporting to country $\widetilde{k}$ ($\tau_{\widetilde{k}}$). Thus to analyze how government policy impacts world welfare we can examine changes in WW_i and WW_j separately.

Before proceeding further, it is useful to solve for the socially optimal level of R&D. To this end, differentiating world welfare over good k (WW_k) with respect to firm k's quality (q_k) and solving the obtained first-order condition yield:

$$q_k^w(\gamma_{kk}, \gamma_{\widetilde{k}k}) = \frac{\mu_k(\gamma_{kk} + 3) + \mu_{\widetilde{k}}(\gamma_{\widetilde{k}k} + 3)}{8\delta_k} \quad \text{for } k = i, j$$

Comparing q_k^w with the profit-maximizing level of R&D q_k^I establishes the following result:

Lemma 2. *Firms underinvest in R&D relative to the socially optimal level* q_k^w*, i.e.* $q_k^I < q_k^w$ for $k = i, j$.

The intuition for Lemma 2 is clear: when choosing their R&D investments, firms only consider their profits and do not take into account the positive effects of their R&D on consumers.

3 Benchmark case: symmetric countries

In this section we analyze the benchmark model with symmetric countries. Focusing on the symmetric case makes it easier to identify the fundamental channels through which patent and trade policies take effect.[14] Particularly, we make the following assumption:

Assumption 1 (Symmetry): $m_k = m$; $n_k = n$; $\mu_k = \mu$; $\gamma_{kk} = \gamma_d$; $\gamma_{k\widetilde{k}} = \gamma_f$; $\delta_k = \delta$ *for* $k = i, j$.

Note that Assumption 1 implies that countries have identical imitation capacities for copying the products of their own firms (i.e. γ_d) as well as foreign firms (i.e. γ_f). This assumption does not drive our results and is made primarily for expositional ease.

[14] We discuss the case of asymmetric countries in Section 4.1.

3.1 Patent protection with exogenous tariffs

We begin by assuming exogenous tariff barriers and characterizing each country's unilateral incentives for patent protection. First consider each country's decision regarding its national patent protection Ω_{kk}. Recall that country k's own patent protection Ω_{kk} only affects its national welfare derived from good k, w_{kk}. Let

$$\Delta w_{kk} = w_{kk}(\Omega_{kk} = P, \Omega_{\widetilde{k}k} = I) - w_{kk}(\Omega_{kk} = I, \Omega_{\widetilde{k}k} = I) \tag{15}$$

denote country k's welfare change from extending patent protection to its own firm, given that the firm does not receive patent protection abroad. Then, it can be shown that

$$\Delta w_{kk} > 0 \text{ if and only if } \gamma_d > \widehat{\gamma}_d = \frac{(1-\gamma_f)(1-\tau_{\widetilde{k}})}{2} \tag{16}$$

Hence, country k chooses to protect its own firm if and only if the technological capacity for imitation in its market is sufficiently large. The trade-off underlying this policy is as follows. On one hand, offering the firm patent protection benefits local consumers since it incentivizes the firm to invest more R&D which raises the quality of its product. On the other hand, by shutting down production of the imitated version of the local firm's product, patent protection hurts consumers in two ways. One, it reduces variety and those consumers that prefer the imitated product to the original (because they find it to be a better deal in terms of quality adjusted price) lose access to their preferred product. Two, the lack of competition from the imitated product allows the firm to charge a higher price for the original product.[15] It follows that when γ_d is high enough, the benefit of own patent protection outweighs its costs, making it optimal for a country to grant patent protection to its firm.[16]

How do country k's incentives for protecting its own firm depend on country $\widetilde{k}$'s patent protection policy with respect to the firm? It is straightforward to show that

$$\frac{\partial \widehat{\gamma}_d}{\partial \gamma_f} < 0 \tag{17}$$

that is, a rise in country $\widetilde{k}$'s imitation capacity with respect to firm k lowers $\widehat{\gamma}_d$ above which country k extends own patent protection. This indicates that a country is *more likely* to protect its own firm that does not receive patent protection from the foreign country. An important implication of this result is that patent protection from abroad serves as a *strategic substitute* for domestic protection.

[15] Thus, our model features the classic trade-off between the dynamic benefits and static costs of patent protection (Nordhaus, 1969).

[16] We provide supporting calculations in the appendix for this and other results established in the paper.

Next consider the impact of foreign tariff barriers on country k's incentives for protecting its firm. It is easily checked that

$$\frac{\partial \widehat{\gamma}_d}{\partial \tau_{\widetilde{k}}} < 0 \tag{18}$$

i.e., an increase in country $\widetilde{k}$'s import tariff lowers $\widehat{\gamma}_d$ thereby making it more attractive for country k to implement own patent protection. Intuitively, a higher foreign tariff undermines domestic firm's R&D incentives by reducing its overseas profit. This in turn increases the marginal benefit of a country's own patent protection since it becomes more important for stimulating R&D. We can now state the following:

Lemma 3: *(i) A country has a unilateral incentive to implement own patent protection iff the local capacity for imitation is sufficiently strong, i.e.* $\Delta w_{kk} > 0$ *iff* $\gamma_d > \widehat{\gamma}_d$*.*

(ii) An increase in the intensity of imitative competition facing its firm in the foreign market raises a country's incentive to extend patent protection to its firm (i.e. $\partial \widehat{\gamma}_d / \partial \gamma_f < 0$*).*

(iii) An increase in foreign tariff barriers makes a country more likely to protect its own firm (i.e. $\partial \widehat{\gamma}_d / \partial \tau_{\widetilde{k}} < 0$*).*

Now consider country k's incentives for protecting the foreign firm. Note that this policy decision affects country k's welfare only over good $\widetilde{k}$, i.e. $w_{k\widetilde{k}}$. Let

$$\Delta w_{k\widetilde{k}} = w_{k\widetilde{k}}(\Omega_{k\widetilde{k}} = P, \Omega_{\widetilde{k}\widetilde{k}} = I) - w_{k\widetilde{k}}(\Omega_{k\widetilde{k}} = I, \Omega_{\widetilde{k}\widetilde{k}} = I) \tag{19}$$

be country k's welfare change from extending patent protection to the foreign firm, assuming the firm receives no patent protection from its own country. It can then be shown that

$$\Delta w_{k\widetilde{k}} > 0 \text{ if and only if } \gamma_f > \widehat{\gamma}_f = \frac{4\tau_k^2 + 2\gamma_d \tau_k - 8\tau_k - 3\gamma_d + 5}{(1-\tau_k)(3-2\tau_k)} \tag{20}$$

In other words, a country chooses to offer patent protection to the foreign firm if its technological capacity to imitate the foreign product is high enough. The intuition behind this result is the following. Protecting the foreign firm benefits a country through two channels. First, it benefits domestic consumers by increasing the foreign firm's R&D that improves the quality of its product.[17] Second, it raises the tariff revenue paid by the foreign firm due to its higher sales in the importing country. This is a novel gain from patent protection which does not arise under free trade. On the other hand,

[17] Note that protecting the foreign firm also raises its profit in the home market. But when setting its patent policy, the home country does not take this into account since the foreign firm's profits do not contribute to its welfare.

protecting the foreign firm also incurs two types of costs on domestic consumers. One, it eliminates their access to the imitated foreign good. Two, it allows the foreign firm to raise its price in the domestic market. For sufficiently high γ_f, the benefits of extending patent protection to the foreign firm dominate its costs, making it optimal to offer such protection.

It can be further calculated that

$$\frac{\partial \widehat{\gamma}_f}{\partial \gamma_d} < 0 \tag{21}$$

i.e. the threshold value of γ_f above which country k protects firm $\widetilde{k}$ falls with the other country's imitation capacity with respect to its own firm's product. Thus a country is less likely to protect the foreign firm if it receives patent protection in its own country. This implies that each country's own patent protection is a *strategic substitute* for the other country's foreign protection.

How does a country's import tariff affect its incentives for protecting the foreign firm? It is straightforward to show the following

$$\frac{\partial \widehat{\gamma}_f}{\partial \tau_k} > 0 \text{ if and only if } \tau_k > \widehat{\tau}_k = \frac{3\gamma_d + 1 - \sqrt{2(1-\gamma_d)}}{2(\gamma_d + 1)} \tag{22}$$

that is, a tariff reduction by country k increases its incentive to protect the foreign firm if and only if the initial tariff level is high. It follows that the impact of country k's tariff on its incentives for extending foreign patent protection is non-monotonic (it has an inverted U-shape). To gain some intuition, note that a reduction in a country's import tariff has two conflicting effects on its incentive for extending patent protection to the foreign firm. On the one hand, it improves the profitability of the country's market to the foreign firm, which increases the effectiveness of the country's patent protection in enhancing the foreign firm's incentive for R&D. This tends to make a country more willing to protect the foreign firm (a complementary effect). On the other, a reduction in tariff barriers *per se* increases the foreign firm's R&D incentives and this tends to lower the marginal benefit of foreign patent protection. This makes the country less willing to protect the foreign firm (a substitution effect). When country k's import tariff τ_k is high, a reduction in τ_k implies a stronger innovation stimulating effect of its foreign patent protection so that the complementary effect dominates, and country k is more likely to grant foreign patent protection. We summarize as follows:

Lemma 4: *(i) A country provides foreign patent protection if and only if its capacity to imitate the foreign firm is sufficiently high, i.e.* $\Delta w_{k\widetilde{k}} > 0$ *if and only if* $\gamma_f > \widehat{\gamma}_f$.

(ii) An increase in the intensity of imitative competition facing the foreign firm in its local market raises a country's incentive to extend patent protection to the foreign firm (i.e. $\partial\widehat{\gamma}_f/\partial\gamma_d < 0$*).*

(iii) A reduction in its import tariff increases a country's incentive to extend patent protection to the foreign firm if its initial tariff is high whereas it decreases it when the initial tariff is low, i.e. $\partial\widehat{\gamma}_f/\partial\tau_k > 0$ *if and only if* $\tau_k > \widehat{\tau}_k$.

Lemma 4 yields a novel insight about the interaction between a country's tariff and non-tariff barriers. In our model, weaker patent protection works much like a non-tariff barrier that reduces a firm's profitability in a foreign market. The result above suggests that non-tariff barriers may rise in response to tariff reductions only if tariffs fall from already low levels. Interestingly, this finding seems consistent with the increasing concern about the growing prevalence of non-tariff barriers since that is more likely to happen in an environment where tariffs are low (as they indeed are today relative to historical levels).

As mentioned, parts (i) of Lemma 3 and 4 together indicate that patent protection levels of individual countries for the same firm are strategic substitutes for one another. A direct implication is that countries have an incentive to free ride on each other's patent protection. The strategic substitutability between national patent policies also arises in models of variety-expanding innovation such as Grossman and Lai (2004).[18] Our analysis shows that such a pattern of strategic interaction in patent policies holds regardless of whether innovation is horizontal or vertical in nature.

Before proceeding, we establish a useful result that follows readily from Lemma 4:

Corollary 1: $\frac{\partial\widehat{\gamma}_f}{\partial\tau_k}|_{\gamma_d=0} > 0$ *for all* $0 \leq \tau_k < 1$.

Corollary 1 says that provided a firm receives patent protection in its own country, a tariff reduction by the other country makes it more willing to protect the firm. When a firm receives patent protection in its own market, the other country's tariff policy is less important for determining its overall R&D incentive. As a result, the substitution effect of a tariff reduction on a country's benefit from foreign patent protection is dominated by its complementary effect, so that it is more willing to protect the foreign firm when its own tariff is lower.

[18] It is worth noting that Grossman and Lai consider a CES aggregate innovation function with labor and human capital as inputs. In their model, patent protections across countries are strategic substitutes only when $\beta \leq 0$ where β represents the substitutability between labor and human capital in the innovation process. But they argue that this case should be most realistic, as when $\beta \leq 0$ patent protection exhibits diminishing returns, i.e. innovation rises at a lower rate as patent protection continues to increase.

3.2 Equilibrium patent policies

We now derive equilibrium patent policies. It is useful to start by analyzing each country's decision about extending foreign patent protection assuming it necessarily protects its own firm. Specifically, we have $\gamma_d = 0$ for both countries when domestic patent protection is enforced. Applying Lemma 4 it is easy to see that countries extend foreign patent protection to each other if and only if $\gamma_f > \widehat{\gamma}_f|_{\gamma_d=0} > 1$. Since this is impossible given $\gamma_f < 1$, we can state the following result:

Proposition 1: *Assume that each country grants patent protection to its own firm. Then, in Nash equilibrium, each country denies patent protection to the foreign firm, i.e.*

$$(\Omega_i^*, \Omega_j^*) = (\{P, I\}, \{P, I\})$$

Proposition 1 says that countries have no incentives to protect foreign firms if they *already* receive patent protection in their own countries. Note that this is true regardless of a country's tariff barriers (τ_k) and its imitation capacity with respect to the foreign firm (γ_f). This result is driven by profit considerations: when a country grants patent protection to the foreign firm, it does not benefit from the increased profit earned by that firm which accrues solely to the foreign country. As a result, the total benefit of extending foreign patent protection is not sufficient for covering its cost and it proves optimal to deny protection to the foreign firm.[19]

Note that Proposition 1 also implies that *discriminatory* patent policies arise in equilibrium since, given that domestic firms are protected in both countries, foreign firms are not. Empirical evidence indicates that discriminatory patent policies indeed arise in the real world. For example, de Rassenfosse et al. (2019) and Webster et al. (2014) examine patent granting in five major countries (i.e. U.S., Japan, EU, Korea, and China) which together account for about 80 percent of global patenting activity and find that patent offices in these countries are more likely to grant patents to domestic firms relative to foreign firms. Mai and Stoyanov (2019) examine data on Canadian IP rights cases and find that Canadian firms are more likely to protect their IP rights relative to non-Canadian firms. Furthermore, they demonstrate that such ruling decisions by Canadian courts are aligned with national welfare maximization principles.

We now analyze the case where countries choose both domestic and foreign patent protections. Recall from Lemma 3 that when countries do not protect each other's firms, they choose to protect their own firms if and only if $\gamma_d > \widehat{\gamma}_d$. Then, Proposition 1 implies that for all $\gamma_d > \widehat{\gamma}_d$ the Nash equilibrium must be such that each country only

[19] It is worth noting that the incentive to deny patent protection to foreign firms is also a feature of models with variety-expanding innovation (Geng and Saggi, 2015).

implements own patent protection. Now consider $\gamma_d < \widehat{\gamma}_d$. In this case the damage that imitation causes to firm profits is minor so that countries do not protect their own firms regardless of foreign patent policy. Another way of stating this result is that some degree of imitative competition is welfare-improving even when R&D incentives are taken into account. Moreover, it is easy to see that countries do not grant foreign protection as well, as the incentives to protect foreign firms are even weaker than that for domestic firms. Thus, we obtain the Nash equilibrium outcome as follows:

Proposition 2: *Suppose countries are free to choose their domestic and foreign patent protection policies. Then, in equilibrium, if $\gamma_d > \widehat{\gamma}_d$ both countries provide patent protection to only their local firms whereas when $\gamma_d \leq \widehat{\gamma}_d$ they protect neither firm.*

Proposition 2 has two interesting implications. First, it indicates that the lack of foreign patent protection can be a robust equilibrium outcome. That is, countries choose to not extend protection to foreign firms even if they can optimize over both foreign and domestic patent protection. Note that since such an equilibrium outcome arises for all levels of tariffs, an important policy implication is that a shallow trade agreement that only involves the exchange of tariff concessions between countries would not be effective in inducing them to strengthen their patent protection towards each other. In this case, provided more protection for foreign firms is socially desirable, a trade agreement such as TRIPS that *directly* coordinates patent policies across countries would be necessary. The second key implication of Proposition 2 is that although tariff reductions cannot prevent discriminatory patent policies when $\gamma_d > \widehat{\gamma}_d$, they do help temper countries' incentives for engaging in such discrimination. To see this, note that as τ_k falls $\widehat{\gamma}_d$ rises, implying that countries facing lower foreign tariffs are less likely to make use of own patent protection. This in turn reduces the gap between a country's domestic and foreign patent protection, i.e. it lowers the degree of discrimination in the country's patent policy.

3.3 Requiring international patent protection

We have seen that a salient feature of Nash equilibrium policies is the lack of patent protection extended to foreign innovators. In this section, we ask if this outcome is inefficient and whether it can be remedied by following *national treatment* in international patent protection, a policy regime under which both countries must extend the same patent protection to foreign firms that they do to local firms. Such a policy regime is empirically relevant and can be considered, for example, as capturing the Patent Cooperation Treaty which has been shown to help reduce discrimination in national patent policy (de Rassenfosse et al., 2019). To this end, we assume parameter values are such that countries have a unilateral incentive to provide patent protection to their own firms (i.e. $\gamma_d > \widehat{\gamma}_d$).[20] The key question, therefore, is whether asking them to also protect foreign firms raises welfare.

Recall that world welfare WW is additively separable in the two goods, i.e. $WW = WW_i + WW_j$. Moreover, since countries are symmetric and country k's extending patent protection to firm $\widetilde{k}$ affects $WW_{\widetilde{k}}$ but not WW_k, it is sufficient to focus on the coordination that requires country k to grant patent protection to firm $\widetilde{k}$. Let

$$\Delta WW_{\widetilde{k}} = WW_{\widetilde{k}}(\Omega_{k\widetilde{k}} = P, \Omega_{\widetilde{k}\widetilde{k}} = P) - WW_{\widetilde{k}}(\Omega_{k\widetilde{k}} = I, \Omega_{\widetilde{k}\widetilde{k}} = P) \tag{23}$$

denote the change in world welfare over good $\widetilde{k}$ due to country k's granting of patent protection to firm $\widetilde{k}$. Then it can be shown that

$$\Delta WW_{\widetilde{k}} > 0 \text{ if and only if } \gamma_f > \overline{\gamma}_f \tag{24}$$

i.e. the granting of patent protection by country $\widetilde{k}$ to the foreign firm improves world welfare if and only if country $\widetilde{k}$'s imitation capacity with respect to that firm is sufficiently high. The intuition for this result is the following. On one hand, requiring a country to protect the foreign firm necessarily lowers its own welfare because, left to its own devices, it prefers not to do so in equilibrium. On the other, granting patent protection to the foreign firm creates two positive externalities for the foreign country. One, it raises the foreign firm's global profit by eliminating imitation of its good. Two, it increases foreign consumer surplus by incentivizing the foreign firm to invest more in quality improving R&D. For sufficiently high γ_f, a firm's R&D investment becomes too low when it faces imitation in the other country. When this is the case, extending patent protection to foreign firms is socially optimal.

We next examine the role of tariff barriers in shaping the welfare impact of international patent protection. First, it can be readily shown that $\overline{\gamma}_f < 0$ if and only if $\tau_k < 1/2$. Since $\gamma_f > 0$ by assumption, we have $\gamma_f > \overline{\gamma}_f$ for all γ_f. It follows that when each country's tariff is sufficiently low, extending patent protection to the foreign firm necessarily improves world welfare. On the other hand, we have $\overline{\gamma}_f > 1$ if and only if $\tau_k > \sqrt{3} - 1$. Since $\gamma_f < 1$ this implies that $\gamma_f < \overline{\gamma}_f$ for all γ_f. Thus, mandating national treatment in international patent protection necessarily lowers world welfare when each country's tariff is high. Thus we can state the following:

[20] The analysis for the case where $\gamma_d < \widehat{\gamma}_d$ is analogous but a bit more tedious. Note that when domestic patent protection is absent, extending foreign protection leads countries to discriminate against their own firms. While such an outcome is consistent with the principle of national treatment (which requires foreign firms to be treated *no worse* than domestic ones), we do not think it is of great practical interest.

Proposition 3: *The welfare effects of implementing national treatment in international patent protection, i.e. a policy under which countries extend the same patent protection to foreign firms that they do to domestic firms, depend on tariff levels. In particular, when tariffs are low, i.e.* $\tau_k < 1/2$*, national treatment in international patent protection increases global welfare whereas when tariffs are sufficiently high, i.e.* $\tau_k > \sqrt{3} - 1$*, it lowers it.*[21]

Importantly, Proposition 3 highlights the key role tariff barriers play in shaping the welfare impact of national treatment in international patent protection. The intuition for this finding is by now crystal clear. Lower tariff barriers make foreign markets more profitable so that R&D incentives of firms become more responsive to changes in patent protection abroad. This increases the effectiveness of foreign patent protection in incentivizing innovation. In addition, lower tariffs raise the domestic consumer surplus derived from the purchase of foreign goods, thus reducing the static cost of foreign patent protection. Both of these forces reinforce each other and increase the welfare gains delivered by foreign patent protection, making its implementation more socially desirable. Interestingly, Proposition 3 is consistent with the observation that the world's major multilateral IP agreement (i.e. TRIPS) was successfully negotiated only *after* average tariffs in the world had been reduced substantially via several successful rounds of multilateral trade negotiations since the formation of GATT in 1947. Moreover, it also helps explain why TRIPS incorporates the clause of national treatment as a core principle: such an institutional arrangement is more likely to be justified on welfare grounds when member countries impose low tariffs on each other.

Proposition 3 also suggests that Nash equilibrium patent protection may be too weak from a social welfare perspective. To see this, simply note that, left to their own devices, countries *never* protect foreign firms (Proposition 2) whereas extending such protection can be socially optimal for low tariff barriers. Intuitively, such under-protection occurs because of the positive externalities a country's patent protection generates on its trading partner. Since countries do not take such cross-border spillovers into account when acting non-cooperatively, they end up providing insufficient patent protection to foreign firms.[22]

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[21] When tariffs are of intermediate magnitude, i.e. $1/2 < \tau_k < \sqrt{3} - 1$, (24) shows that protecting foreign firms raises world welfare when the intensity of competition generated by foreign imitation is high, i.e. $\gamma_f > \overline{\gamma}_f$; but reduces it when $\gamma_f < \overline{\gamma}_f$.

[22] It is worth noting that the result that Nash equilibrium policies induce insufficient patent protection may depend on the institutional rule that is in place. For example, while it has been shown that under-protection of patents may occur in the absence of any institutional constraints as well as under national treatment (Grossman and Lai, 2004; Geng and Saggi, 2015), Geng and Saggi (2020) argue that under the principle of *mutual recognition*, Nash equilibrium policies can lead to *over-protection* of patents.

3.4 If tariffs are optimally chosen

The previous section explains how exogenously given tariff barriers affect the desirability of national treatment in international patent protection. We next allow countries to choose their import tariffs along with their patent policies. In particular, we consider two scenarios depending on whether countries coordinate their tariffs. In the first scenario, countries non-cooperatively choose their tariffs to maximize their national welfare. In the second case, countries coordinate their tariffs to maximize global welfare. A central question of interest is how tariff coordination may affect the welfare implications of national treatment in international patent protection.[23]

To begin, note that each country's import tariff only affects its welfare over the foreign good. In light of welfare being additively separable over the two goods, this implies that tariffs chosen by the two countries are independent of each other. Hence we can analyze each country's optimal tariff separately.

Consider the first scenario where tariffs are determined non-cooperatively. Given the equilibrium patent protection described in Proposition 2, each country chooses its import tariff to maximize its national welfare

$$\max_{\tau_k} w_{k\tilde{k}}(\tau_k) \tag{25}$$

It is easy to show that there exists a unique optimal level of tariff that maximizes country k's welfare

$$\tau_k^{na} = \frac{3-5\gamma_f}{4(1-\gamma_f)} \tag{26}$$

Note that $\tau_k^{na} \geq 0$ if and only if $\gamma_f \leq 3/5$, i.e. each country's optimal trade policy is an import tariff if $\gamma_f \leq 3/5$ and is an import subsidy otherwise. To restrict our attention to import tariffs we focus on the case where $\gamma_f \leq 3/5$.

The intuition underlying the determination of the nationally optimal tariff τ_k^{na} is as follows. Each country faces both a benefit and a cost when raising its import tariff. The benefit is the tariff revenue the country collects from the foreign firm, while the cost is the fall in domestic consumer surplus that results from the reduction in the foreign firm's R&D.[24] When a country's capacity to imitate the foreign product is weak (i.e.

[23] For simplicity, we maintain our assumption that countries always protect their own firms, although the argument remains qualitatively the same even when this assumption is relaxed.

[24] In particular, since there is no strategic interaction between firms, tariffs do not have any profit-shifting effects in our model. Moreover, an import tariff does not affect domestic consumers through the price channel since it is absorbed by the foreign firm.

$\gamma_f < 3/5$), the benefit of tariff protection dominates the cost so that it is optimal for the country to choose a strictly positive import tariff. It is also readily checked that

$$\frac{\partial \tau_k^{na}}{\partial \gamma_f} < 0 \tag{27}$$

i.e. each country's optimal tariff decreases in its imitation capacity with respect to the foreign product. Intuitively, a higher γ_f dampens the foreign firm's R&D incentives and lowers the quality of its product. As a result, each country's import volume as well as tariff revenue fall. This in turn reduces the nationally optimal tariff.

Now consider each country's incentive for extending patent protection to the foreign firm when it charges its optimal import tariff. It is easy to see that when a country chooses to protect the foreign firm from local imitation, its equilibrium tariff becomes $\tau_k^{na}|_{\gamma_f=0} = 3/4$. Plugging $\tau_k^{na}|_{\gamma_f=0}$ and τ_k^{na} into country k's welfare over good $\widetilde{k}$ we can show that

$$w_{k\widetilde{k}}(P, P, \tau_k^{na}|_{\gamma_f=0}) - w_{k\widetilde{k}}(P, I, \tau_k^{na}) < 0 \tag{28}$$

i.e. granting foreign patent protection necessarily *lowers* country k's welfare when it sets its tariff optimally. It follows that countries do not extend patent protection to each other even when they are free to use their optimal tariffs.

A natural question, then, is whether mandating the provision of foreign protection is socially desirable under Nash equilibrium tariffs. To see the answer, simply substitute $\tau_k^{na}|_{\gamma_f=0}$ and τ_k^{na} into the world welfare functions to obtain

$$WW_{\widetilde{k}}(P, P, \tau_k^{na}|_{\gamma_f=0}) - WW_{\widetilde{k}}(P, I, \tau_k^{na}) < 0 \tag{29}$$

that is, extending foreign patent protection necessarily *lowers* world welfare under nationally optimal tariffs.[25] Thus, we can state the following:

Proposition 4: *Suppose countries choose tariffs non-cooperatively. Then, in Nash equilibrium, (i) each country grants patent protection to only its local firm and (ii) requiring national treatment in international patent protection unambiguously lowers world welfare.*

Part (i) of Proposition 4 indicates that the lack of foreign patent protection in Nash equilibrium arises regardless of whether tariffs are exogenously given or endogenously determined. Part (ii) of the proposition implies that countries have no incentive to

[25] In fact, the result is even stronger in the sense that when tariffs are optimally chosen a *marginal* decrease in the intensity of imitation reduces global welfare, i.e. $\partial WW_{\widetilde{k}}(\tau_k^{na})/\partial \gamma_f > 0$.

coordinate their patent policy by extending patent protection to each other's firm. This is an important result; it clarifies that if tariff policies are non-cooperatively set, requiring national treatment in international patent protection is actually counterproductive. Hence, this result captures a plausible scenario under which the TRIPS agreement harms global welfare, a concern that has been raised by many policy-makers and researchers (see, for example, Boldrin and Levine, 2013).

It is worth explaining the intuition behind Proposition 4. In particular, we already know from Proposition 3 that requiring national treatment increases welfare when import tariffs are low and exogenously fixed. So why does welfare necessarily fall when tariffs are endogenous? The reason is that countries *raise* their optimal tariffs if they have to extend patent protection to each other – see equation (27). This tariff increase results in a *reduction* in the foreign firm's R&D as opposed to an increase that one might expect from a strengthening of patent protection that it faces. In fact, it is easy to calculate that firm $\widetilde{k}$'s choice of quality under country k's optimal tariff τ_k^{na} is given by

$$q_{\widetilde{k}}(\tau_k^{na}(\gamma_f);\gamma_f) = \frac{\mu(\gamma_f - 2\gamma_d + 5)}{16\delta_{\widetilde{k}}}$$

Observe that $q_{\widetilde{k}}$ *increases* in γ_f. Since R&D is already under-provided by firms (see Lemma 2), the decline in R&D caused by the increase in tariff protection that accompanies national treatment in patent protection lowers global welfare. Thus, the indirect negative effect of the tariff increase on R&D incentives caused by extending patent protection to the foreign firm turns out to dominate the direct positive effect of such protection. As a result, requiring national treatment in international patent protection reduces world welfare when tariff policies of countries are unconstrained so that they end up imposing optimal tariffs on one another. This result underscores the crucial role that restraints on trade policy play in creating a meaningful role for international patent protection.

Next, we show that trade policy coordination between countries that eliminates internal tariffs is sufficient for national treatment in international patent protection to be welfare improving. To see this, suppose that countries coordinate their tariffs so as to maximize their joint welfare. Then simply differentiating $WW_{\widetilde{k}}$ with respect to τ_k to obtain

$$\frac{\partial WW_{\widetilde{k}}}{\partial \tau_k} < 0 \text{ for all } 0 \leq \tau_k, \gamma_f < 1 \tag{30}$$

that is, the marginal social value of raising a country's import tariff is negative regardless of the level of the tariff and the status of patent protection. Notably, this finding is consistent with the well-known efficiency-reducing properties of import tariffs. However, the channel through which import tariffs work against efficiency is different in our context. More specifically, an import tariff is inefficient in our model because it reduces the foreign firm's R&D investment, which in turn hurts consumers in both countries.[26]

Given that tariffs are welfare-reducing, tariff coordination calls for the elimination of tariffs regardless of patent policies. Comparing this outcome with the Nash equilibrium, we see that nationally optimal tariffs are too high relative to the social optimum. Intuitively, an increase in a country's import tariff hurts the foreign country in two ways. One, it lowers the foreign firm's profit. Two, it discourages the foreign firm's R&D investment, which in turn lowers the foreign product's quality and the surplus enjoyed by foreign consumers. Since countries do not take these negative cross-border spillovers into account, they end up choosing inefficiently high import tariffs.

Next consider the determination of patent policies under free trade. From Proposition 1 we know that the removal of tariff barriers does not change the Nash equilibrium patent policies since countries do not grant patent protection to foreign firms regardless of the levels of their tariffs. Nevertheless, Proposition 3 implies that trade coordination that removes the tariff barriers indeed makes it jointly optimal for countries to extend patent protection to each other's firm. Hence we have the following proposition:

Proposition 5: *If countries coordinate both trade and patent policies they eliminate tariffs and follow national treatment in patent protection. Such a policy outcome yields strictly higher welfare than when international coordination occurs only over tariffs or patent protection (but not both).*

Proposition 5 says that tariff coordination can help ensure that a regime of national treatment in international patent protection is welfare superior to one where countries only protect their own firms. This is an important result as it indicates that trade coordination yields welfare gains not just by liberalizing world trade, but can also lead to additional welfare improvement by potentially inducing international coordination over patent policies. At a broad level, Proposition 5 makes a case for the tenet that shallow integration targeting border policies (e.g. import tariffs) can facilitate deeper integration involving behind-the-border policies (e.g. patent protection). In this way, Proposition 5 helps explain why TRIPS was negotiated after the GATT/WTO system

[26] In our model, an import tariff is completely borne by the foreign firm, thus leading to a lump-sum transfer of profit from the foreign firm to the importing country. Although this might appear to be a somewhat peculiar feature of our model, we regard it as an advantage because it allows us to identify the welfare-reducing effect of tariffs through their impact on innovation while controlling for other well-understood efficiency implications of tariffs. It is worth noting that empirical studies reveal that tariff pass through could occur and can be asymmetric between countries (Feenstra, 1989; Cavallo et al., 2021). Incorporating these features into the analysis of tariff and patent policies is an interesting direction for future research.

had succeeded in substantially lowering global tariff barriers, i.e. the success of traditional trade liberalization efforts under the GATT/WTO system may have contributed to the ratification of TRIPS.[27]

4 Further analysis

This section examines two extensions of our benchmark model. First, we relax the assumption that markets are symmetric across countries and consider the case where one country has a larger market demand than the other. This extension is important given the fact that there is great tension between developed and developing countries over the protection of IPRs. Second, we incorporate R&D subsidies into the analysis. This extension is of policy relevance as the WTO allows countries to subsidize R&D. Our main goal is to analyze how these empirically relevant features affect incentives for patent protection, both with and without national treatment. For ease of exposition, we maintain the assumption that countries always enforce own patent protection (i.e. $\gamma_d = 0$) and focus on their decisions about protecting foreign firms. Our results remain qualitatively unchanged when countries are free to deny patent protection to local firms.

4.1 Market size asymmetry

In this section we incorporate market asymmetry between countries into the benchmark model. Specifically, we assume one country (e.g. country i) has a larger market demand for both goods than the other (e.g. country j), which implies that $\mu_i > \mu_j$. In this way, the extended model can be considered as a North-South one where country i (j) is the North (South).[28] To identify the fundamental channels of interest, we abstract from R&D subsidies and focus on each country's incentives for setting its foreign patent protection.

[27] Both Propositions 4 and 5 would remain qualitatively unchanged under continuous patent policy such that each country chooses the level of its imitation intensity γ_f. First note that under non-cooperative tariffs, it is easy to show that world welfare derived from either good is strictly increasing in γ_f. This implies that strengthening foreign patent protection as required by national treatment necessarily reduces world welfare. On the other hand, under free trade, world welfare derived from either good is strictly decreasing in γ_f. Hence, under free trade, social optimality requires each country to enforce maximum level of foreign patent protection, i.e. $\gamma_f = 0$ so that national treatment necessarily improves welfare.

[28] One could also allow for supply side asymmetry by assuming R&D effectiveness δ to be different across countries. This will not change our results given that δ proportionally affects the cost and the benefit of patent protection and therefore drops out in the equations. That being said, if there exists a fixed cost of enforcing patent protection that is weakly lower in the North, which is likely the case, then it is straightforward to show that the North has a stronger incentive to protect patents, the same result that obtains under market size asymmetry.

The first interesting observation we can make is that relative market size shapes the effect of tariff reductions on a country's incentives for extending foreign patent protection (e.g. $\Delta w_{k\widetilde{k}}$). Recall that part (*iii*) of Lemma 4 shows that under symmetry, tariff reductions are first complementary and then substitutable for increasing foreign patent protection, with the tariff cutoff for the two opposing effects being $\widehat{\tau}_k$. Given asymmetric countries, $\widehat{\tau}_k$ becomes a function of μ_k and $\mu_{\widetilde{k}}$ so that one can show

$$\frac{\partial \widehat{\tau}_k}{\partial \mu_k} > 0 \tag{31}$$

Importantly, condition (31) says that a larger country is *less likely* to see tariff reductions as complementary for its foreign protection. In fact, as μ_k becomes sufficiently high, $\widehat{\tau}_k$ can be greater than one so that tariff reductions always yield the substitution effect. This is because for a larger country the foreign (smaller) market is not highly profitable, so a fall in the foreign tariff does not create much additional incentives for the larger country to protect the foreign firm. The reverse of this logic is also true, that is, a smaller country is more likely to see tariff reductions as complementary for its foreign patent protection as the foreign market is relatively more profitable. In fact, it is easy to show that $\widehat{\tau}_k$ falls below zero as μ_k becomes sufficiently low.

Next, it can be shown that

$$\Delta w_{k\widetilde{k}} > 0 \text{ if and only if } \gamma_{k\widetilde{k}} > \gamma_{k\widetilde{k}}^{na} = \frac{4\mu_k\tau_k^2 - 6\mu_k\tau_k - 2\mu_{\widetilde{k}}\tau_k + 2\mu_k + 3\mu_{\widetilde{k}}}{\mu_k(1-\tau_k)(3-2\tau_k)} \tag{32}$$

that is, each country extends its foreign patent protection if and only if its imitation capacity with respect to the foreign firm is sufficiently large. Moreover, we can calculate that

$$\frac{\partial \gamma_{k\widetilde{k}}^{na}}{\partial \mu_k} < 0 \tag{33}$$

and

$$\frac{\partial \gamma_{k\widetilde{k}}^{na}}{\partial \mu_{\widetilde{k}}} > 0 \tag{34}$$

Importantly, (33) and (34) say that each country's tendency to offer foreign patent protection increases in domestic demand but decreases in foreign demand. On one hand, larger domestic demand has two opposing effects on a country's gain from offering foreign patent protection. It increases the foreign firm's R&D incentives and reduces the gain for the country to protect the firm's patent. Meanwhile, it also implies a greater benefit for domestic consumers from improvement in the quality of the foreign good, which increases the gain from protecting the foreign firm. The second positive effect turns out to dominate so that a country is more likely to protect the foreign firm when its domestic market is larger. On the other hand, larger foreign demand raises the foreign firm's R&D incentives and this reduces the gain for the home country from further extending patent protection to the foreign firm.

An important implication of the above observations is that as market size becomes more asymmetric across countries, the national incentives for patent protection diverge. In particular, the country with the larger market is more likely to protect the foreign firm whereas the opposite is true for the smaller country. Recall that when countries are identical they deny patent protection to each other in equilibrium. It follows that in an asymmetric equilibrium, the smaller country never chooses to protect the foreign firm as its incentive for doing so become is weaker relative to the symmetric case. By contrast, the larger country may choose to offer foreign patent protection if its market is sufficiently bigger.

The above findings also suggest that patent coordination between asymmetric countries should focus on the strengthening of patent protection in small countries. To see this, first note that

$$\Delta WW_{\widetilde{k}} > 0 \text{ if and only if } \gamma_{k\widetilde{k}} > \gamma_{k\widetilde{k}}^{so} = \frac{\tau_k(2\mu_k\tau_k - 2\mu_k + \mu_{\widetilde{k}})}{\mu_k(1-\tau_k)(2-\tau_k)} \tag{35}$$

that is, it is socially optimal for country k to protect the foreign firm if and only if its imitation capacity with respect to the foreign firm is sufficiently large. Moreover, direct calculations show that

$$\gamma_{k\widetilde{k}}^{na} - \gamma_{k\widetilde{k}}^{so} > 0 \tag{36}$$

i.e. the socially optimal threshold of $\gamma_{k\widetilde{k}}^{so}$ is lower. It follows that each country's equilibrium foreign protection is too weak relative to the social optimum. As discussed before, this occurs because countries do not take into account the positive externalities of their patent policies on each other. We can further define $d_k^{\gamma} = \gamma_{k\widetilde{k}}^{na} - \gamma_{k\widetilde{k}}^{so}$ as a measure of the degree of under-protection in equilibrium, with a larger d_k^{γ} indicating more severe under-protection and a greater need for patent coordination. It can then be shown that

$$\frac{\partial d_k^{\gamma}}{\partial \mu_k} < 0 < \frac{\partial d_k^{\gamma}}{\partial \mu_{\widetilde{k}}} \tag{37}$$

that is, the value of implementing national treatment declines with the market size of the larger country but rises in that of its trading partner. Intuitively, as a country's market gets larger it is more willing to protect the foreign firm and this is aligned with socially optimality. On the other hand, when the foreign market expands both individual and social incentives for protecting the foreign firm fall. But individual incentives decline faster so that the gap between nationally and socially optimal foreign protection increases. It follows that d_k^γ decreases in country k's relative market demand, indicating that there is a greater need for smaller countries to strengthen their foreign patent protection.

Now suppose countries non-cooperatively choose their import tariffs. In this case, country k's optimal import tariff is given by

$$\tau_k^{na} = \frac{\mu_k + 2\mu_{\widetilde{k}} - 5\mu_k \gamma_{k\widetilde{k}}}{4\mu_k(1 - \gamma_{k\widetilde{k}})} \tag{38}$$

It is easily shown that

$$\frac{\partial \tau_k^{na}}{\partial \mu_k} < 0 \tag{39}$$

Hence a country's optimal import tariff *decreases* in its market size, which implies that smaller countries tend to impose higher import tariffs than larger ones. Interestingly, this result is consistent with the evidence that richer countries tend to implement lower tariff rates, as provided in Naito (2019). Naito further develops a Ricardian model to show that the observed pattern of tariff rates may be due to richer countries caring more about the negative growth effect of tariffs. Here, we offer an alternative explanation that is more relevant when R&D activity is relevant: richer countries may prefer lower tariffs because they derive more welfare gains from foreign innovations.

As mentioned, a country with smaller domestic market benefits less from innovation so that it has weaker incentives to encourage foreign R&D by setting lower tariff barriers. Substituting τ_k^{na} and $\tau_k^{na}|_{\gamma_{k\widetilde{k}}=0}$ into $\Delta WW_{\widetilde{k}}$ we obtain that

$$\Delta WW_{\widetilde{k}} < 0 \tag{40}$$

Hence, requiring asymmetric countries to extend patent protection to each other necessarily reduces world welfare if Nash tariffs are in place. This suggests that trade coordination is needed for patent coordination to be potentially socially optimal. To see this is indeed the case, note that (30) also holds when countries are asymmetric, which implies that trade policy coordination would lead to zero tariffs between countries. Then it is straightforward to show that

$$\Delta WW_{\widetilde{k}}|_{\tau_k=0} > 0 \tag{41}$$

so that patent coordination improves welfare under free trade. This implies that our results under country symmetry remain qualitatively unchanged when countries differ with respect to market size.[29]

[29] Our analysis has been focused on demand side asymmetry. It is worth noting how asymmetry in

4.2 R&D subsidies

In this section we allow each country to subsidize its own firm's R&D investment. Our goal is to examine the interactions between R&D and patent policies, as well as the implications of such interaction for national treatment in patent protection. To highlight the role of R&D subsidies, in what follows we assume tariffs are zero (although our analysis applies to any exogenous levels of import tariffs). The analysis below delivers three key messages: one, allowing countries to use R&D subsidies reduces the gains from patent protection; two, coordination over R&D subsidies eliminates the need for patent protection; three, world welfare tends to be higher with R&D subsidies since they are more effective in incentivizing innovation than patent protection.

We begin by examining the implications of exogenous R&D subsidies for patent policies. First consider the Nash equilibrium where countries non-cooperatively choose their patent policies. In this case, country k's R&D subsidy s_k affects firm k's R&D decision, which in turn impacts both countries' incentives for extending patent protection to firm k. We can show that

$$\frac{\partial \Delta w_{kk}}{\partial s_k} < 0 \text{ and } \frac{\partial \Delta w_{\widetilde{k}k}}{\partial s_k} < 0 \tag{42}$$

i.e. an increase in country k's R&D subsidy reduces the welfare gains for both countries from granting patent protection to firm k. Thus, as expected, from each country's point of view a R&D subsidy works as a substitute for patent protection. It follows that the use of R&D subsidy by one country makes both countries less likely to enforce patent protection. Importantly, this implies that the presence of R&D subsidies does not change each country's equilibrium patent policy toward the foreign firm: since countries do not extend patent protection to each other in the absence of R&D subsides, they would continue to follow the same policy even when R&D subsidies are available.[30]

the supply side such as imitative capability (i.e. $\gamma_{ij} \neq \gamma_{ji}$) may affect countries' choices of tariff and patent policies. First, (27) indicates that a country's optimal tariff decreases in its imitation capacity for the foreign good, so that countries with better imitation capacity tend to impose lower tariffs. This is because a country's greater imitation capacity lowers the R&D incentives of foreign innovators. As a result, the country needs to reduce its tariff to incentivize foreign innovation. The same logic indicates that countries with stronger imitative capabilities also have a stronger incentive to enforce patent protection (see also part (*ii*) of Lemma 4). In addition, our welfare results remain quantitatively unchanged when countries have asymmetric imitative capability. Assume symmetric market size without loss of generality. Then, we can show that $WW_{\widetilde{k}}(P, P, \tau_k^{na}|_{\gamma_{k\widetilde{k}}=0}) - WW_{\widetilde{k}}(P, I, \tau_k^{na}) < 0$ for $k, = i, j$. Thus, national treatment under Nash tariffs remains welfare-reducing when imitation capacity varies between countries. Moreover, the calculations in Section 4.1 (as in the appendix) also show that national treatment is welfare-improving under free trade when imitative capacity differs across countries.

[30] We can show that R&D subsidies also make countries less likely to protect their own firms.

How do (exogenous) R&D subsidies affect the desirability of strengthening patent protection given to foreign firms? It can be shown that

$$\Delta WW_k > 0 \text{ if and only if } \gamma_f > \overline{\gamma}_f = \frac{6s_k}{\mu} \tag{43}$$

i.e. coordination improves world welfare if and only if γ_f is sufficiently high. Further note that $\partial\overline{\gamma}_f/\partial s_k > 0$ so that higher R&D subsidies raise the threshold of γ_f above which national treatment is socially optimal. Therefore, the presence of R&D subsidies reduces the incentives for countries to offer patent protection to foreign firms. The intuition for this result is clear: when R&D subsidies can be used to fund innovation, patent protection becomes less important for achieving the same objective. A direct implication is that when coordination of international patent protection is not ensured, the availability of R&D subsidies can help improve global innovation and welfare. This insight offers a potential explanation for why R&D subsidies are not prohibited under the WTO even though they may distort trade and undermine competition: given the prevalent failure to adequately protect foreign innovators' patent rights, allowing countries room to employ R&D subsidies is conducive to fostering innovation incentives.

Next consider endogenous R&D subsidies. We examine two scenarios depending on whether R&D subsidy coordination is present: in the first countries non-cooperatively choose their R&D subsidies while in the second they coordinate their R&D subsidies to maximize joint welfare. In the absence of coordination over R&D subsidy, it can be shown that the R&D subsidy s_k that maximizes country k's welfare is given by

$$s_k^{na} = \frac{\mu_k}{8} \tag{44}$$

Thus it is optimal for each country to use a strictly positive R&D subsidy. Intuitively, firms do not take account of the positive externality of their R&D on domestic consumers. Therefore, a R&D subsidy is needed to address the loss in domestic consumer surplus due to inadequate innovation undertaken by its firm.[31] Also note that $\partial s_k^{na}/\partial\mu_k > 0$ so that the optimal R&D subsidy of a country is increasing in its market size. The intuition is that a larger domestic market implies greater gains in domestic consumer surplus from innovation, making it is optimal for the country to set a higher R&D subsidy. Substituting s_k^{na} into $\overline{\gamma}_f$, we see that under nationally optimal R&D subsidies countries benefit from national treatment in patent protection if $\gamma_f > 3/4$. Therefore, even though patent protection becomes less important in the presence of R&D subsidies, the under-protection of patents remains when R&D subsidies are unilaterally determined.

[31] This explains why s_k depends only on the market characteristics of country k but not that of the foreign country.

Now suppose countries coordinate their R&D subsidies to maximize joint welfare. Differentiating world welfare with respect to s_k and solving the associated first order condition yields the socially optimal R&D subsidy:

$$s_k^{so} = \frac{\mu_k(3\gamma_f + 1) + \mu_{\widetilde{k}}}{8} \tag{45}$$

It is easy to see that $s_k^{so} > s_k^{na}$, i.e. nationally optimal R&D subsidies are too low from the social point of view. This is because each country, when acting non-cooperatively, does not take into account the positive externality of its R&D subsidy on foreign consumers. Substituting s_k^{so} into $\overline{\gamma}_f$ we know that national treatment in patent protection increases world welfare iff $\gamma_f > 9\gamma_f/4 + 3/2$, which can never hold. This implies that under coordinated R&D subsidies, the Nash equilibrium policy outcome (featuring no foreign patent protection) is indeed socially optimal. The reason is simply that R&D subsidies are more effective than patent protection in stimulating innovation since they strengthen R&D incentives without enhancing monopoly power. As a result, coordination over R&D policy allows countries to achieve optimality without resorting to patent protection. In fact, it can be shown that world welfare is always higher under R&D policy coordination than under patent coordination in the absence of R&D subsidies. Therefore, coordination over R&D subsidies can be a more desirable substitute for patent coordination.[32]

5 Conclusion

This paper investigates the implications of tariff barriers for international patent protection. To this end, we develop a simple model of trade and quality-upgrading innovation. Our analysis highlights the key role that tariff barriers play in determining the welfare implications of requiring national treatment in patent protection, a policy regime wherein foreign firms are granted the same level of patent protection as domestic ones. We show that tariff barriers affect incentives for patent protection in non-obvious ways. For example, the lower the import tariff of a country, the weaker the incentive of the *other* country to grant patent protection to its own firm since the ability to earn higher profits abroad makes its patent policy a less crucial determinant of its firm's R&D incentive.

As in past literature, we find that national patent protection policies tend to act as strategic substitutes and that countries have an incentive to under-protect foreign firms relative to domestic ones. However, this does not necessarily imply that implementing

[32]One could also allow countries to subsidize imports instead of R&D. It can be shown that import subsidies, like R&D subsidies, are more effective than patent protection in incentivizing innovation as they do not give firms greater monopoly power.

national treatment in international patent protection is welfare-improving. More specifically, we find that requiring a country to follow national treatment in patent protection raises welfare only if its import tariff is low. Furthermore, if countries are free to impose optimal tariffs on each other, national treatment in patent protection actually *lowers* welfare. This key result establishes the importance of negotiating down tariff barriers *prior* to imposing disciplines on national patent policies. The fact that the actual historical experience of countries is consistent with this finding is rather reassuring: after all, multilateral disciplines on intellectual property policies (as captured by the TRIPS agreement) came into existence only after decades of trade liberalization had been undertaken by the GATT/WTO system. Our analysis shows why such a particular sequencing of policy reforms – i.e. multilateral trade liberalization followed by international patent coordination – makes sense from an economic welfare perspective.

6 Appendix

We provide proofs and supporting calculations for the results reported in the paper.

Proof of Lemma 1.

(i) It is straightforward to calculate that

$$\frac{\partial q_k^I}{\partial \gamma_{kk}} = -\frac{\mu_k}{4\delta_k} < 0$$

$$\frac{\partial q_k^I}{\partial \gamma_{\tilde{k}k}} = -\frac{\mu_{\tilde{k}}(1-\tau_{\tilde{k}})}{4\delta_k} < 0$$

$$\frac{\partial q_k^I}{\partial \tau_{\tilde{k}}} = -\frac{\mu_{\tilde{k}}(1-\gamma_{\tilde{k}k})}{4\delta_k} < 0$$

(ii) We calculate that

$$\frac{\partial q_k^I}{\partial \mu_k} = \frac{1-\gamma_{kk}}{4\delta_k} > 0$$

$$\frac{\partial q_k^I}{\partial \mu_{\tilde{k}}} = \frac{(1-\gamma_{\tilde{k}k})(1-\tau_{\tilde{k}})}{4\delta_k} > 0$$

Proof of Lemma 3.

(i) We have

$$\Delta w_{kk} = \frac{\mu^2 \gamma_d A_1(\gamma_d, \gamma_f, \tau_{\tilde{k}})}{32\delta}$$

where $A_1(\gamma_d, \gamma_f, \tau_{\tilde{k}}) = (1 - \gamma_f)\tau_{\tilde{k}} + 2\gamma_d + \gamma_f - 1$. It is easy to check that $\Delta w_{kk} = 0$ iff

$$\gamma_d = \widehat{\gamma}_d = \frac{(1 - \gamma_f)(1 - \tau_{\tilde{k}})}{2}$$

Note that the sign of Δw_{kk} is the same as that of $A_1(\gamma_d, \gamma_f, \tau_{\tilde{k}})$. Hence, to show that $\Delta w_{kk} > 0$ iff $\widehat{\gamma}_d < \gamma_d < 1$ we only need to show $A_1(\gamma_d, \gamma_f, \tau_{\tilde{k}}) > 0$ iff $\widehat{\gamma}_d < \gamma_d < 1$. To this end, note that $\partial A(\gamma_d, \gamma_f, \tau_{\tilde{k}})/\partial\gamma_d = 2 > 0$ so that $A_1(\gamma_d, \gamma_f, \tau_{\tilde{k}})$ is increasing in γ_d. Given $A_1(\gamma_d, \gamma_f, \tau_{\tilde{k}}) = 0$ it must be the case that $A_1(\gamma_d, \gamma_f, \tau_{\tilde{k}}) > 0$ iff $\widehat{\gamma}_d < \gamma_d < 1$. It follows that $\Delta w_{kk} > 0$ iff $\gamma_d > \widehat{\gamma}_d$.

(ii) It is straightforward to check that

$$\frac{\partial \widehat{\gamma}_d}{\partial \gamma_f} = -\frac{1}{2}(1 - \tau_{\tilde{k}}) < 0$$

(iii) It is straightforward to check that

$$\frac{\partial \widehat{\gamma}_d}{\partial \tau_{\tilde{k}}} = -\frac{1}{2}(1 - \gamma_f) < 0$$

Proof of Lemma 4.

(i) We have

$$\Delta w_{k\tilde{k}} = \frac{\mu^2 \gamma_f A_2(\gamma_d, \gamma_f, \tau_k)}{32\delta}$$

where $A_2(\gamma_d, \gamma_f, \tau_k) = 2(\gamma_f - 2)\tau_k^2 - (2\gamma_d + 5\gamma_f - 8)\tau_k + 3\gamma_d + 3\gamma_f - 5$. It can be calculated that $\Delta w_{k\tilde{k}} = 0$ iff

$$\gamma_f = \widehat{\gamma}_f = \frac{4\tau_k^2 + 2(\gamma_d - 4)\tau_k - 3\gamma_d + 5}{(1 - \tau_k)(3 - 2\tau_k)}$$

Since the sign of $\Delta w_{k\tilde{k}}$ is the same as that of $A_2(\gamma_d, \gamma_f, \tau_k)$, it is sufficient to show $A_2(\gamma_d, \gamma_f, \tau_k) > 0$ iff $\widehat{\gamma}_f < \gamma_f < 1$. To this end, we can calculate that $\partial A_2(\gamma_d, \gamma_f, \tau_k)/\partial\gamma_f = (1 - \tau_k)(3 - 2\tau_k) > 0$ so that $A_2(\gamma_d, \gamma_f, \tau_k)$ is increasing in γ_f. By $A_2(\gamma_d, \gamma_f, \tau_k) = 0$ at

$\gamma_f = \widehat{\gamma}_f$, we must have $A_2(\gamma_d, \gamma_f, \tau_k) > 0$ iff $\widehat{\gamma}_f < \gamma_f < 1$. It follows that $\Delta w_{k\widetilde{k}} > 0$ iff $\gamma_f > \widehat{\gamma}_f$.

(ii) It is straightforward to check that

$$\frac{\partial \widehat{\gamma}_f}{\partial \gamma_d} = -\frac{1}{1-\tau_i} < 0$$

(iii) We can calculate that

$$\frac{\partial \widehat{\gamma}_f}{\partial \tau_k} = -\frac{A_3(\gamma_d, \tau_k)}{(1-\tau_k)^2(3-2\tau_k)^3}$$

where $A_3(\gamma_d, \tau_k) = 4(\gamma_d +)\tau_k^2 - (12\gamma_d + 4)\tau_k + 9\gamma_d - 1$. Solving $\frac{\partial \widehat{\gamma}_f}{\partial \tau_k} = 0$ yields two solutions: $\tau_k = (3\gamma_d + 1 + \sqrt{2(1-\gamma_d)})/(2(\gamma_d + 1))$ and $\tau_k = (3\gamma_d + 1 - \sqrt{2(1-\gamma_d)})/(2(\gamma_d + 1))$. But $\tau_k > 1$ cannot be a solution given $0 \leq \tau_k < 1$, so the only feasible solution for $\partial \widehat{\gamma}_f / \partial \tau_k = 0$ is τ_k. To show $\partial \widehat{\gamma}_f / \partial \tau_k > 0$ iff $\widehat{\tau}_k < \tau_k < 1$, we only need to show $A(\tau_k) < 0$ iff $\widehat{\tau}_k < \tau_k < 1$. To this end, note that $\partial A(\tau_k)/\partial \tau_k = 0$ iff $\tau_k = (3\gamma_d + 1)/(2(\gamma_d + 1))$ and $\partial^2 A(\tau_k)/\partial \tau_k^2 = 8(\gamma_d + 1) > 0$. This implies that $\partial A(\tau_k)/\partial \tau_k > 0$ iff $\tau_k > (3\gamma_d + 1)/(2(\gamma_d + 1))$. Moreover, we have $(3\gamma_d + 1 + \sqrt{2(1-\gamma_d)})/(2(\gamma_d + 1)) < (3\gamma_d + 1)/(2(\gamma_d + 1))$, indicating that $A(\tau_k)$ first decreases and then increases for $\widehat{\tau}_k < \tau_k < 1$. It is easy to show that $\lim_{\tau_k \to 1} A(\tau_k) = \gamma_d - 1 < 0$, which together with $A(\tau_k) = 0$ at τ_k imply that $A(\tau_k) < 0$ for $\widehat{\tau}_k < \tau_k < 1$. Hence $\partial \widehat{\gamma}_f / \partial \tau_k > 0$ for $\widehat{\tau}_k < \tau_k < 1$. As a final step, let us show $\partial \widehat{\gamma}_f / \partial \tau_k < 0$ for $0 < \tau_k < \widehat{\tau}_k$. But this must be the case given that $A(\tau_k)$ is decreasing to 0 over $0 < \tau_k < \widehat{\tau}_k$ so that $A(\tau_k) > 0$ for $0 < \tau_k < \widehat{\tau}_k$.

Proof of Corollary 1.

Direct calculations show $(\partial \widehat{\gamma}_f / \partial \tau_k)|_{\gamma_d = 0} = (1 + 4\tau_k - 4\tau_k^2)/((1-\tau_k)^2(3-2\tau_k)^2) > 0$ for all $0 \leq \tau_k < 1$.

Proof of Proposition 1.

Given countries enforce own patent protection, firms face no imitation domestically. This implies that $\widehat{\gamma}_f|_{\gamma_d=0} = (4\tau_k^2 - 8\tau_k + 5)/((1-\tau_k)(3-2\tau_k)) > 1$. Hence it is impossible to have $\gamma_f > \widehat{\gamma}_f|_{\gamma_d=0}$, which implies that countries would not protect the foreign firms given they already enforce own patent protection.

Proof of Proposition 4.

Direct calculations show how foreign patent protection affects national welfare under endogenous tariffs

$$w_{k\widetilde{k}}(\tau_k^N|_{\gamma_f=0}) - w_{k\widetilde{k}}(\tau_k^N) = -\frac{\mu^2\gamma_f(10+\gamma_f)}{256\delta} < 0$$

Moreover, one can calculate how foreign patent protection affects national welfare under endogenous tariffs

$$WW_{\widetilde{k}}(\tau_k^N|_{\gamma_f=0}) - WW_{\widetilde{k}}(\tau_k^N) = -\frac{\mu^2\gamma_f(3\gamma_f+34)}{512\delta} < 0$$

Calculations about the effects of import tariffs on world welfare.

Direct calculations show that

$$\frac{\partial WW_{\widetilde{k}}}{\partial \tau_k} = -\frac{\mu^2(1-\gamma_f)[2(1-\gamma_f)\tau_k + 3(\gamma_d+\gamma_f)+2]}{32\delta} < 0$$

whenever $\tau_k > 0$.

Calculations in Section 4.1

We have

$$\gamma_{k\widetilde{k}}^{na} - \gamma_{k\widetilde{k}}^{so} = \frac{2(2\mu_k + 3\mu_{\widetilde{k}} - 2\mu_k\tau_k - 2\mu_{\widetilde{k}}\tau_k)}{\mu_k(2-\tau_k)(3-\tau_k)} > 0$$

Defining $d_k^\gamma = \gamma_{k\widetilde{k}}^{na} - \gamma_{k\widetilde{k}}^{so}$, we calculate

$$\frac{\partial d_k^\gamma}{\partial \mu_k} = \frac{2\mu_{\widetilde{k}}}{\mu_k(2-\tau_k)} < 0$$

$$\frac{\partial d_k^\gamma}{\partial \mu_{\widetilde{k}}} = \frac{2}{\mu_k(2-\tau_k)} > 0$$

Under Nash tariffs, we have

$$\frac{\partial \tau_k^{na}}{\partial \mu_k} = -\frac{\mu_{\widetilde{k}}}{2\mu_k^2(1-\gamma_{k\widetilde{k}})} < 0$$

When country k extends foreign patent protection to conform to national treatment, the changes in world welfare under Nash tariffs and free trade are calculated respectively as

$$\Delta WW_{\widetilde{k}}|_{\tau_k=\tau_k^{na}} = -\frac{\mu_k\gamma_{k\widetilde{k}}(3\mu_k\gamma_{k\widetilde{k}} + 18\mu_k + 16\mu_{\widetilde{k}})}{512} < 0$$

and

$$\Delta WW_{\widetilde{k}}|_{\tau_k=0} = \frac{1}{16}\mu_k^2\gamma_{k\widetilde{k}}^2 > 0$$

Calculations in Section 4.2

Regarding the effects of R&D subsidy on the welfare gains from patent protection, we have

$$\frac{\partial \Delta w_{kk}}{\partial s_k} = -\frac{3\mu\gamma_d}{8\delta} < 0$$

and

$$\frac{\partial \Delta w_{\widetilde{k}k}}{\partial s_k} = -\frac{\mu\gamma_f(3-2\tau_{\widetilde{k}})}{8\delta} < 0$$

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