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Tariffs and Foreign Direct Investment in a Dynamic North–South Model

This paper examines how import tariffs by a developed country (the North) and a developing country (the South) affect innovation and foreign direct investment (FDI) using a quality ladder model. We show that a Northern import tariff raises the relative wage of Northern labor, but impedes innovation and FDI. This may worsen Northern welfare. By contrast, a Southern import tariff raises the relative wage of Southern labor and promotes innovation and FDI. This can improve Southern welfare. These imply that the South has a stronger incentive than the North to impose an import tariff, which is consistent with actual observation.

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RECENTLY, THE U.S. GOVERNMENT HAS adopted a protectionist policy concerning some aspects of international trade. As evidence, Fajgelbaum et al. (2020, p. 9) reported that in 2018, the U.S. increased average import

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tariffs on about \$247 billion worth of Chinese products from 3.0% to 15.5%. They also showed that in the same year, China increased in retaliation the average tariff on about \$93 billion worth of U.S. exports from 8.4% to 18.9%. For an explanation for the initial U.S. action, according to a presidential memorandum signed on March 22, 2018, the increased tariffs by the U.S. targeting China were at least partly in response to allegedly insufficient protection by China of the intellectual property of U.S. companies. The question then naturally arises as to what effect increased tariffs by a developed country (hereinafter, the North) and a developing country (hereinafter, the South) have, given that intellectual property rights (IPR) are not well protected in the South.

In this paper, we theoretically investigate the effects of import tariffs on innovation, foreign direct investment (FDI), wages, and welfare using a North–South growth model based on the quality ladder-type product-cycle model first developed by Grossman and Helpman (1991). In our model, a higher quality product invented in the North replaces the current product if innovation occurs through successful research and development (R&D). The Northern inventor can then choose to produce in the North or shift production to the South through FDI to employ its lower wage labor. However, some of these goods produced in the South are subject to imitation because of its imperfect protection of IPR. If Southern firms imitate a good, the Northern inventor cannot earn profits. Unlike Grossman and Helpman, we assume that each government imposes an *ad valorem* tariff on imported goods.

We provide the following four main results. First, a unilateral increase in the Northern tariff impedes innovation and FDI, although it also raises the relative wage of Northern to Southern labor. In the Northern market, an increased Northern tariff raises the duty-inclusive price of the goods produced in the South. This protects firms producing in the North against Southern firms that can potentially produce lower quality goods. Therefore, a tariff increase by the North enables the Northern firms to raise the price in the Northern market and enjoy higher profits. However, a higher Northern tariff also raises the duty-inclusive price of the goods produced by firms that have shifted production from the North to the South. This reduces the demand for these goods in the Northern market, so that an increased Northern tariff decreases the profits of the FDI firms. Through both these effects, an increased Northern tariff reduces the incentive for FDI from the North to the South. In addition, it raises the Northern relative wage because more firms choose to produce in the North. The higher Northern wage also leads to a higher cost of R&D in the North, and thus, an increased Northern tariff impedes innovation.

Second, contrary to the effects of the Northern tariff, a unilateral increase in the Southern tariff raises the Southern relative wage and promotes innovation and FDI. An increased Southern tariff raises the duty-inclusive price of the Northern goods in the Southern market if the pretariff price is unchanged. Therefore, firms producing in the North need to lower the pretariff price of the goods sold in the South when the Southern tariff increases. Otherwise, they would lose the Southern market due to the entry of Southern firms producing lower quality goods. The price reduction also decreases the profits of any firm that chooses to produce in the North, such that it increases the incentive for FDI into the South to avoid the tariff. Because the increased production transfer from the North to the South reduces the Northern relative wage and thereby the cost of R&D in the North, any tariff increase by the South promotes innovation.

Third, a unilateral tariff increase by the North tends to worsen Northern welfare if the Southern tariff is lower and the imitation rate in the South is higher. In that case, the welfare-maximizing tariff rate for the North is zero. Our model reveals that an increased Northern tariff affects Northern welfare through the following four channels:

(i) impeding innovation,
(ii) decreasing the number of cheaper goods supplied by Southern imitators,
(iii) raising the (duty-inclusive) prices of goods, and
(iv) increasing the income of Northern households.

A tariff increase by the North then exerts a positive effect on Northern welfare because it raises Northern income by shifting production from the South to the North. However, if the Southern tariff is low and imitation is active, fewer Northern firms undertake FDI and production in the South tends to be smaller, even before the Northern tariff is raised. As a result, the positive effect of a Northern tariff increase on Northern income weakens under a low Southern tariff and active imitation. Accordingly, in that case, the negative welfare effects from the decreased innovation and increased prices tend to dominate the positive welfare effect due to the increased income of the North.

Finally, in contrast to the North, a unilateral tariff increase by the South improves the welfare of the South if the initial tariff rate is lower than some certain positive level. Therefore, the welfare-maximizing tariff rate for the South is strictly positive. In our model, an increase in the Southern tariff affects Southern welfare through the following three channels:

(i) enhancing innovation,
(ii) increasing the number of cheaper imitated goods, which originates from the increase in FDI into the South, and
(iii) changing the tariff revenue of the Southern government.

If the initial tariff rate is sufficiently low, the first and second positive welfare effects dominate and the increased tariff rate by the South improves its welfare. This implies that the South has a stronger incentive to raise the tariff than the North.

The effects of trade cost have already been examined in a number of studies using quality ladder-type growth models.[1] Seminal studies include Dinopoulos and Segerstrom (1999a, 1999b) and Dinopoulos and Syropoulos (1997). However, both studies assumed two structurally identical countries, that is, a North–North setting. By contrast, we focus on trade policy in two asymmetric countries: a North that is in-

1. Using expanding variety as opposed to quality ladder-type growth models, Baldwin and Robert-Nicoud (2008), Dinopoulos and Unel (2011), Gustafsson and Segerstrom (2010), Impullitti and Licandro (2018), Naito (2017), and Sampson (2016) also investigated the effects of trade costs.

novative and a South that is the recipient of production transfers. Our results show that a tariff increase by a country has differing effects depending on whether the country is the North or the South, which is not possible in a North–North setting. Dinopoulos and Segerstrom (2007) also constructed a North–South model where a Southern firm can produce some state-of-the-art good through imitation, and considered how decreasing trade cost affects both innovation and imitation. However, they assumed the trade cost to be symmetric in both countries, and thus did not analyze either the case of asymmetric trade costs or the effects of a unilateral tariff increase by just one country. Therefore, it was unclear whether the Northern and Southern tariff increases have differing effects. By contrast, our model allows unequal tariff rates between the North and the South so that we can readily investigate the effect of a unilateral tariff increase. Grieben and Şener (2009) also examined the effects of a Northern and Southern unilateral tariff reduction in a North–South product-cycle model. However, they assumed imitation by Southern firms to be the only channel for technology diffusion from the North to the South and did not consider FDI, much like Dinopoulos and Segerstrom.

Unlike these studies, we incorporate production transfers by Northern firms in our model. As pointed out by Keller (2004), FDI is one of the major channels for technology diffusion across countries. Moreover, with so-called tariff-jumping FDI, tariffs are likely to affect the incentive for FDI and thus labor demand.[2] Our model captures this tariff effect not previously considered in Dinopoulos and Segerstrom (2007) and Grieben and Şener (2009). In addition, unlike either of these previous studies, we examine the welfare effects of a unilateral tariff increase.[3] To date, many theoretical studies, including Kennan and Riezman (1988) and Syropoulos (2002), have concluded that the optimal tariff for a large country tends to be high. However, as discussed by Naito (2019), in practice we frequently observe the opposite: economically larger countries tend to set lower tariffs. The results of the welfare analysis in our model are consistent with these actual tendencies regarding country size and tariffs because our model shows that the Northern tariff worsens the welfare of the North under a certain condition, whereas the Southern tariff improves the welfare of the South if the initial tariff rate is set sufficiently low.

The remainder of the paper is structured as follows. Section 1 develops the North–South quality ladder model with tariffs and Section 2 derives the market equilibrium path. Section 3 presents the comparative statics and Section 4 provides the welfare analysis. Section 5 concludes.

2. For example, Belderbos and Sleuwaegen (1998), Chen and Moore (2010), and Ghodsi (2020) empirically showed that tariffs imposed by a host country exert a significantly positive effect on FDI to that country, which is consistent with the tariff-jumping motive.

3. Several studies have examined the welfare effects of changes in unilateral tariffs in a two-country model, for example, Gros (1987), Opp (2010), and Felbermayr, Jung, and Larch (2013). However, these employ static as opposed to growth models.

1. THE MODEL

We introduce FDI into the two-country quality ladder model developed by Grossman and Helpman (1991). Consider an economy consisting of two countries, the North and the South, denoted N and S, respectively. We assume perfect capital mobility between the countries so that their interest rates equalize. With a fixed number (measure) of identical households, let $L_i(0)$ denote the number of households in country $i \in \{N, S\}$. A member of each household supplies one unit of labor inelastically at each time point. Assume that the member size of each household is unity at the initial time and grows at a constant rate $g_L(\geq 0)$, such that the quantity of labor supplied in country i at time t is given by $L_i(0)e^{g_L t} \equiv L_i(t)$. We select Southern labor as the numeraire and normalize the Southern wage to be unity at every time point.

There is a continuum of goods, indexed by $\omega \in [0, 1]$, produced in the North or the South. One unit of good output requires one unit of labor input. Each good is classified by a countable infinite number of "generations" $j = 0, 1, 2, \ldots$. We normalize the generation number at the initial time to be zero for all goods. If innovation occurs in industry ω, a one-step new generation of good ω is developed. Therefore, generation j of good ω can be produced after the jth innovation in industry ω. As described in Section 1.3, innovation occurs because of successful R&D efforts by a Northern firm. Different generations of a good possess different "qualities." The quality of generation j of good ω is $q(j, \omega) = \lambda^j$, where the rate of quality increase between any two consecutive generations, λ (> 1), is identical for all goods.

The government of each country imposes an *ad valorem* tariff on imported goods. The tariff rate of country i is τ_i (≥ 0), which is common to all imported goods. The government transfers all the tariff revenues to the households of its country as a lump sum and runs a balanced budget at each time point.

1.1 Households

Each household in country i maximizes the lifetime utility $U_i = \int_0^\infty e^{-(\rho - g_L)t} \log u_i(t)dt$, where ρ $(> g_L)$ is a common subjective discount rate and $\log u_i(t)$ represents instantaneous utility at time t. We specify the instantaneous utility function as:

$$\log u_i(t) = \int_0^1 \log \left[\sum_j q(j, \omega) d_i(j, \omega, t) \right] d\omega, \tag{1}$$

where $d_i(j, \omega, t)$ denotes the per capita consumption of good ω of generation j at time t. The intertemporal budget constraint of each household in country i is given by

$$\int_0^\infty e^{-\int_0^t r(s)ds + g_L t} E_i(t)dt = A_i(0) + \int_0^\infty e^{-\int_0^t r(s)ds + g_L t} w_i(t)dt + \int_0^\infty e^{-\int_0^t r(s)ds + g_L t} T_i(t)dt, \tag{2}$$

where $r(t)$ is the interest rate, $E_i(t)$ and $A_i(0)$ denote consumption expenditure per capita and initial asset holdings per capita, respectively, and $w_i(t)$ and $T_i(t)$ denote wages and a lump-sum transfer per capita by the government, respectively.

We solve this utility maximization problem in two stages. First, for each product, a household chooses a single generation $J(\omega, t)$ that carries the lowest quality-adjusted price $p(j, \omega, t)/q(j, \omega)$. This implies the following static demand function:

$$d_i(j, \omega, t) = \begin{cases} E_i(t)/p(j, \omega, t) & \text{for } j = J(\omega, t), \\ 0 & \text{otherwise.} \end{cases} \tag{3}$$

Second, the household chooses a time pattern of expenditure to maximize its lifetime utility. Such intertemporal utility maximization requires that

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

1.2 Production

The firm that developed the current latest generation of good ω (hereinafter, the "leader" firm in industry ω) can produce it monopolistically under IPR protection if the firm chooses to operate in the North. A leader firm can then become a "multinational" firm by shifting production to the South. Following Lai (1998), Glass and Wu (2007), and Tanaka and Iwaisako (2014), we assume that a Northern firm can transfer production to the South instantaneously without cost. However, while the multinational firm enjoys a lower labor cost of production in doing this, it also faces the risk of imitation because the South does not sufficiently enforce IPR protection. If good ω is imitated at time t, the leader firm in industry ω cannot earn profits for time t because perfect competition with copied goods prevails in the industry at that time. For simplicity, we assume that whether a good is produced by imitation is determined independently at each time point. More specifically, if a leader firm chooses to produce a good in the South, Southern firms imitate that good at some constant probability $m \in [0, 1)$ at any time point.[4] Therefore, given the law of large numbers, $m \times 100$ percent of all multinational firms are imitated at any time point. We interpret this imitation probability m as the degree of IPR protection; higher m implies weaker IPR enforcement in the South.

Next, we consider how the price and quantity supplied of each good are determined. Each good is produced by either (i) the leader firm in the North monopolistically, (ii) the multinational firm in the South monopolistically, or (iii) imitators in the South under perfect competition. By assuming that the Northern tariff rate is sufficiently low, we rule out the case where a leader firm produces in both countries to avoid

4. Grossman and Lai (2004) adopt a similar assumption.

tariffs.[5] From (3), a leader firm can maximize profits by selling at the upper limit of the price such that rival firms that could produce an old generation in the same product line cannot operate. For a leader firm, the optimal price in the Northern and Southern markets can differ because of the tariffs.

1.2.1 Northern firms. First, we consider what level of price a leader firm producing in the North charges in the Northern market. We assume that any firm can freely produce generations older than the currently latest in each product line because of expired patents.[6] In this case, leader firms do not undertake R&D because they cannot take more than a one-step quality lead over the nearest follower firms in the same product line. Thus, the potentially strongest rivals for a Northern leader firm are the follower firms that can produce the current second to newest generation of the same good. A follower firm could cut the (pretariff) price down to its marginal cost, which would be $w_N(t)$ if produced in the North and $w_S(t) = 1$ if produced in the South. This implies that the lowest possible duty-inclusive price of a follower's good imported from the South to the North is $1 + \tau_N$. Therefore, the optimal price for a Northern leader firm in the Northern market is $\lambda \min\{w_N(t), 1 + \tau_N\}$ because it needs to set the lowest quality-adjusted price to sell the good.

In this paper, we focus on the case where the tariff rate in the North is low enough to satisfy $1 + \tau_N \leq w_N(t)$ (see footnote). Under this assumption, a Northern leader firm prices its good at $p_{NN}(t) = \lambda(1 + \tau_N)$ in the North. The demand for a Northern leader's good by Northern consumers is

$$x_{NN}(t) = \frac{E_N(t)L_N(t)}{\lambda(1 + \tau_N)}. \tag{5}$$

The Northern leader's profits from sales in the North are given by

$$\pi_{NN}(t) = [\lambda(1 + \tau_N) - w_N(t)]\frac{E_N(t)L_N(t)}{\lambda(1 + \tau_N)}. \tag{6}$$

In a similar way, we derive the price a leader firm producing in the North charges in the Southern market. As we focus on the case where the Northern wage is not lower than the Southern wage, a follower firm could set a lower (duty-inclusive) price in the Southern market when it produces in the South than when it produces in the North. To set the lowest quality-adjusted price in the Southern market, a Northern leader firm needs to choose a *duty-inclusive* price not higher than λ because the marginal cost of the follower firm that produced in the South would be equal to $w_S(t) = 1$. Therefore, the optimal *pretariff* price that a Northern leader firm charges Southern consumers

5. In equilibrium, production in both countries is not optimal for a leader firm if and only if $\tau_N < [w_N(t) - 1]/\lambda$. The proof is provided in Appendix B in the Supporting Information.

6. Even without this assumption, leader firms do not undertake R&D, and our results do not change at all if $w_N(t) < (1 - m)\lambda$ and leader firms do not have cost advantage over follower firms in the R&D process. The proof is provided in Appendix C in the Supporting Information.

is $p_{NS}(t) = \lambda/(1+\tau_S)$. As the duty-inclusive price is λ, the demand for a Northern leader's good by Southern consumers is

$$x_{NS}(t) = \frac{E_S(t)L_S(t)}{\lambda}. \tag{7}$$

The Northern leader's profits from sales in the South are given by[7]

$$\pi_{NS}(t) = \left[\frac{\lambda}{1+\tau_S} - w_N(t)\right]\frac{E_S(t)L_S(t)}{\lambda}. \tag{8}$$

Adding (6) and (8), we obtain the total profits of a Northern leader firm as follows:

$$\pi_N(t) = \left[1 - \frac{w_N(t)}{\lambda(1+\tau_N)}\right]E_N(t)L_N(t) + \left[\frac{1}{1+\tau_S} - \frac{w_N(t)}{\lambda}\right]E_S(t)L_S(t). \tag{9}$$

1.2.2 Multinationals. Next, we consider what level of price a multinational firm charges Northern consumers. For the same reason as in the decision by a Northern leader firm, a multinational firm needs to choose a *duty-inclusive* price not higher than $\lambda \min\{w_N(t), 1+\tau_N\}$ in the North to set the lowest quality-adjusted price. Under the assumption that $1+\tau_N \leq w_N(t)$, the optimal *pretariff* price in the North is $p_{FN}(t) = \lambda$ for a multinational firm. Because the duty-inclusive price is $\lambda(1+\tau_N)$, the demand for an unimitated multinational's good by Northern consumers is

$$x_{FN}(t) = \frac{E_N(t)L_N(t)}{\lambda(1+\tau_N)}. \tag{10}$$

The unimitated multinational's profits from sales in the North are given by

$$\pi_{FN}(t) = (\lambda - 1)\frac{E_N(t)L_N(t)}{\lambda(1+\tau_N)}. \tag{11}$$

We derive the price a multinational firm charges Southern consumers in a similar way. Just as we considered the pricing of a Northern leader firm, a follower firm could set a lower (duty-inclusive) price in the South when it produces in the South. To set the lowest quality-adjusted price, a multinational firm needs to choose a price not higher than λ in the South because the marginal cost would be $w_S(t) = 1$ if a follower firm produced in the South. Therefore, the optimal price in the Southern market is

7. If $1+\tau_S > \lambda/w_N(t)$, a Northern leader firm could not earn positive profits by selling the good in the South. In this case, no Northern leader firm would supply the good in the South, that is, $x_{NS}(t) = 0$. However, we rule out this case.

$p_{FS}(t) = \lambda$ for a multinational firm. The demand for an unimitated multinational's good by Southern consumers is

$$x_{FS}(t) = \frac{E_S(t)L_S(t)}{\lambda}. \tag{12}$$

The unimitated multinational's profits from sales in the South are given by

$$\pi_{FS}(t) = (\lambda - 1)\frac{E_S(t)L_S(t)}{\lambda}. \tag{13}$$

Consequently, from (11) and (13), the total profits of a multinational firm are

$$\pi_F(t) = \left(1 - \frac{1}{\lambda}\right)\left[\frac{E_N(t)L_N(t)}{1+\tau_N} + E_S(t)L_S(t)\right]. \tag{14}$$

1.2.3 Imitated goods. If a good is imitated at time t, any firm in the South can produce and export the latest-generation good at that time. In the Southern market, the price of the good falls to $w_S(t) = 1$, which is equal to the marginal cost of imitators. The demand for an imitated good by Southern consumers then becomes

$$x_{MS}(t) = E_S(t)L_S(t). \tag{15}$$

In the Northern market, an imitated good is imported from the South and sold at $1 + \tau_N$ after tariff.[8] Therefore, the demand for an imitated good by Northern consumers is

$$x_{MN}(t) = \frac{E_N(t)L_N(t)}{1+\tau_N}. \tag{16}$$

1.3 R&D and FDI

Following Grossman and Helpman (1991), we assume an R&D process as follows: if a firm devotes $a_N X(t)\tilde{I}$ units of Northern labor for a time interval of length dt to research good ω, it succeeds in developing the next generation of good ω with probability $\tilde{I}dt$, where a_N is a parameter and $X(t)$ represents the difficulty of R&D. As in Dinopoulos and Segerstrom (1999a), Dinopoulos and Thompson (2000), Şener and Zhao (2009), and others, we assume that the growth rate of $X(t)$ is equal to the growth rate of the total labor supply, g_L, so that the model is free from scale effects.[9] For a finite size of R&D activities in equilibrium, the expected gain from R&D must

8. Under the assumption that $1 + \tau_N \leq w_N(t)$, a leader firm whose good is imitated cannot earn profits, irrespective of whether it produces in the North or the South.

9. Our model can thus be interpreted as an extension of "first-generation" fully endogenous growth models such as in Grossman and Helpman (1991) because our model becomes one if we assume $X(t) = 1$ and $g_L = 0$ for all t.

not exceed the cost of R&D. Thus, letting $v_N(t)$ denote the stock market value of a Northern leader firm, we have:

$$v_N(t) \leq w_N(t)a_N X(t) \text{ with equality if } I(t) > 0, \tag{17}$$

where $I(t)$ denotes the innovation rate at time t, which is assumed to be the same in every industry in the symmetric equilibrium.

Once a Northern firm succeeds in inventing a new-generation good, it can become a multinational firm by shifting production to the South without cost. Therefore, if both Northern leaders and multinational firms exist in equilibrium, the market values of a Northern leader and a multinational firm must be equal. That is, the following equality must be held at each time point:

$$v_N(t) = v_F(t), \tag{18}$$

where $v_F(t)$ denotes the stock market value of a multinational firm.

Next, we consider the no-arbitrage conditions between the stocks of a leader firm and the risk-free asset. If the shareholders of a firm hold a well-diversified portfolio, the expected return from the stocks of a leader firm must be equal to the return from the risk-free asset. The shareholders of a Northern leader firm then earn dividends $\pi_N(t)dt$ and capital gains $\dot{v}_N(t)dt$ over a time interval of length dt. At the same time, the Northern leader firm loses its monopolistic rents through the development of a new generation of the same good by another firm at the innovation rate $I(t)$ over the time interval. Thus, the shareholders are faced with a capital loss of $v_N(t)$ with probability $I(t)dt$. These imply that the no-arbitrage condition with respect to the stocks of a Northern leader firm is[10]

$$r(t)v_N(t) = \pi_N(t) + \dot{v}_N(t) - I(t)v_N(t). \tag{19}$$

A multinational firm earns profits $\pi_F(t)$ if its good is not produced by imitators at time t. This event occurs with probability $1 - m$ at each time point. Meanwhile, because of imitation, the multinational firm cannot earn any profits at time t with probability m. Thus, the expected dividends that shareholders of a multinational firm obtain at time t is $(1 - m)\pi_F(t)$. In addition, over a time interval of length dt, the shareholders obtain capital gains $\dot{v}_F(t)dt$, and are faced with a capital loss of $v_F(t)$ with probability $I(t)dt$ given the loss of monopolistic rent through the development of a new generation of the same good by another firm. Thus, the no-arbitrage condition between the stocks of a multinational firm and the risk-free asset is

$$r(t)v_F(t) = (1 - m)\pi_F(t) + \dot{v}_F(t) - I(t)v_F(t). \tag{20}$$

10. If a Northern leader firm transfers production to the South and becomes a multinational firm, it can obtain the value $v_F(t) - v_N(t)$. However, from (18), this is zero in equilibrium.

1.4 Labor Markets

In the North, labor is devoted to production and R&D activities. Letting $n_N(t) \in (0, 1)$ represent the number (measure) of industries in which the Northern leader firms produce state-of-the-art goods, the aggregate labor demand for production in the North is given by $n_N(t)(x_{NN}(t) + x_{NS}(t))$. The aggregate labor demand for R&D activities is given by $a_N X(t) I(t)$ because firms undertaking R&D target all industries. From (5) and (7), the labor market-clearing condition in the North is

$$n_N(t)\left[\frac{E_N(t)L_N(t)}{\lambda(1+\tau_N)} + \frac{E_S(t)L_S(t)}{\lambda}\right] + a_N X(t)I(t) = L_N(t). \tag{21}$$

In the South, multinational firms and imitators demand labor for production. We define $n_S(t) \equiv 1 - n_N(t)$, which is the number of industries where the goods are produced in the South. The goods produced in the South are imitated at probability m at each time point. Given the law of large numbers, multinational firms monopolistically produce goods in $(1-m)n_S(t)$ industries and Southern imitators produce goods in $mn_S(t)$ industries. The aggregate labor demand of the multinationals is $(1-m)n_S(t)(x_{FN}(t) + x_{FS}(t))$ and that of the Southern imitators is $mn_S(t)(x_{MN}(t) + x_{MS}(t))$. From (10), (12), (15), and (16), the labor market-clearing condition in the South becomes

$$\begin{aligned}(1-m)\,n_S\,(t)&\left[\frac{E_N(t)L_N(t)}{\lambda(1+\tau_N)} + \frac{E_S(t)L_S(t)}{\lambda}\right] \\ &+ mn_S(t)\left[\frac{E_N(t)L_N(t)}{1+\tau_N} + E_S(t)L_S(t)\right] = L_S(t).\end{aligned} \tag{22}$$

1.5 Government Budget Constraints

The Northern government imposes the tariff on imports from the South by the multinational firms and the Southern imitators. In the Northern market, sales of the good supplied by a multinational firm are $p_{FN}(t)x_{FN}(t) = E_N(t)L_N(t)/(1+\tau_N)$ and sales of the good supplied by the Southern imitators are $x_{MN}(t) = E_N(t)L_N(t)/(1+\tau_N)$. Thus, the Northern tariff revenue is given by $n_S(t)\tau_N E_N(t)L_N(t)/(1+\tau_N)$. As the Northern government transfers all tariff revenue to Northern households, it determines the lump-sum transfer per capita $T_N(t)$ to satisfy the following budget constraint at each time point:

$$T_N(t)L_N(t) = n_S(t)\tau_N\frac{E_N(t)L_N(t)}{1+\tau_N}.$$

The Southern government imposes the tariff on imports from the North by the Northern leader firms. Sales of a Northern leader firm in the Southern market are $p_{NS}(t)x_{NS}(t) = E_S(t)L_S(t)/(1+\tau_S)$, which implies that the Southern tariff revenue is given by $n_N(t)\tau_S E_S(t)L_S(t)/(1+\tau_S)$. Therefore, the Southern government determines $T_S(t)$ to satisfy the following budget constraint:

$$T_S(t)L_S(t) = n_N(t)\tau_S \frac{E_S(t)L_S(t)}{1+\tau_S}. \tag{23}$$

2. THE EQUILIBRIUM

In this section, we discuss market equilibrium. To simplify notation, we define world aggregate expenditure as $E(t) \equiv E_N(t)L_N(t) + E_S(t)L_S(t)$ and the share of Northern aggregate expenditure in world aggregate expenditure as $\phi \equiv E_N(t)L_N(t)/E(t)$. On the equilibrium path, ϕ becomes constant over time because $E_N(t)$ and $E_S(t)$ always grow at the same rate given the Euler equation (4). By using $E(t)$ and ϕ, the labor market equilibrium conditions (21) and (22) are rewritten as

$$n_N(t)\left(\frac{\phi}{1+\tau_N} + 1 - \phi\right)\frac{E(t)}{\lambda} + a_N X(t)I(t) = L_N(t), \tag{24}$$

$$(1 - m + m\lambda)n_S(t)\left(\frac{\phi}{1+\tau_N} + 1 - \phi\right)\frac{E(t)}{\lambda} = L_S(t). \tag{25}$$

In this model, there is no state variable, except population size and the difficulty of R&D, whose growth rates are exogenous and constant. Consequently, as shown in the Appendix, this model does not have a transitional process and the economy jumps to the steady state immediately at the initial time. In the steady state, $E_i(t)$, $I(t)$, $n_N(t)$, $n_S(t)$, and $w_N(t)$ are constant over time. We therefore omit the time index of these variables hereinafter. As E_i is constant, the interest rate $r(t)$ is also constant and equal to ρ all the time from (4).

For analytical tractability, we focus on the case where the Southern households initially have no assets.[11] Then, from (2) and (23), the budget constraint of a Southern household is

$$E_S = 1 + n_N E_S \frac{\tau_S}{1+\tau_S}, \tag{26}$$

where the left-hand side (LHS) is expenditure per capita, the first term on the right-hand side (RHS) is wage income, and the second term on the RHS is the per capita

11. Some surveys show that financial assets per capita in many developing countries are less than 10% of those in the U.S. For example, according to OECD Data (https://data.oecd.org/), household financial assets per capita in the U.S. were about 251,000 U.S. dollars in 2018, whereas those in India and Mexico were about 8,000 and 21,000 U.S. dollars, respectively. Appendix B1 of "Allianz Global Wealth Report 2021" also shows that net financial assets per capita in the U.S. were about 218,000 euros in 2021, whereas those in China were about 12,000 euros.

lump-sum transfer from the Southern government's tariff revenue.[12] Because $E_S = (1-\phi)E(t)/L_S(t)$ by the definition of $E(t)$ and ϕ, the budget constraint (26) can be rewritten as $1-\phi = (1+\tau_S)L_S(t)/[(1+\tau_S n_S)E(t)]$. Substituting (25) into this equation to eliminate $E(t)$, we obtain ϕ as a decreasing function of n_S as follows:

$$\frac{\phi}{1-\phi} = (1+\tau_N)\left[\frac{\lambda}{1-m+m\lambda}\frac{1+\tau_S n_S}{(1+\tau_S)n_S} - 1\right]. \tag{27}$$

This equation implies that an increase in n_S has two effects on the share of Southern aggregate expenditure in world aggregate expenditure, $1-\phi$, through the budget constraint of a Southern household. First, as shown in (25), an increase in n_S raises the Southern wage compared with the world aggregate expenditure, $1/E(t)$, because it expands the demand for Southern labor. The increased wage income has a positive effect on $1-\phi$. Second, an increase in n_S reduces the transfer payment to Southern households because it decreases the tariff revenue of the Southern government. The decreased transfer payment has a negative effect on $1-\phi$. Nevertheless, the first effect necessarily dominates the second, so that ϕ is decreasing with n_S, as shown in (27).

Next, to analyze the equilibrium, we describe two key equations with respect to I and n_S. We derive the first equation from the labor market-clearing conditions in the two countries. Combining (24) and (25), we have the following equation:

$$I = \frac{L_N(t)}{a_N X(t)} - \left(\frac{1}{n_S} - 1\right)\frac{1}{1-m+m\lambda}\frac{L_S(t)}{a_N X(t)}. \tag{28}$$

As $X(t)$ grows at the same rate as $L_N(t)$ and $L_S(t)$, the relation between n_S and I satisfying (28) is depicted as an upward sloping curve in Figure 1. We refer to this as the *LC curve* given the labor constraint and it shows the combinations of n_S and I that are consistent with equilibrium in the labor markets of the two countries.

The LC curve is upward sloping because the innovation rate I satisfying the labor constraints increases with n_S for two reasons. First, as n_S increases, the number of industries producing in the North, n_N, contracts, and thus labor demand for production decreases in the North. Second, an increase in n_S reduces the quantity of labor demanded by the Northern leader firm, $[\phi/(1+\tau_N) + 1 - \phi](E(t)/\lambda)$. This second effect results from the increase in the Southern wage compared with the world aggregate expenditure, $1/E(t)$, in the Southern labor market, as shown in (25). A higher Southern wage increases the marginal cost of a follower firm when produced in the South, so that the Northern leader firms raise the relative price of their goods to the world aggregate expenditure and thereby decrease production. Because the above-mentioned effects reduce the labor inputs for production in the North, the Northern

12. We do not explicitly use the budget constraint of a Northern household because it is necessarily satisfied from Walras' Law whenever the other conditions in our model hold. See Appendix D in the Supporting Information.

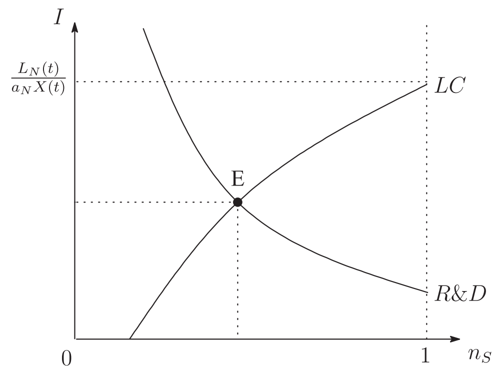

Fig 1. The Equilibrium.

labor resources available for R&D increase. Therefore, an innovation rate I consistent with the equilibrium in the labor markets increases with n_S.

The second equation with respect to n_S and I is derived from the free-entry condition in R&D. Because $v_F(t) = w_N a_N X(t)$ and $\dot{v}_F(t)/v_F(t) = \dot{X}(t)/X(t) = g_L$ from (17) and (18), substituting (14) and (20) into the former yields

$$\frac{(1-m)\left(1-\frac{1}{\lambda}\right)\left(\frac{\phi}{1+\tau_N}+1-\phi\right)E(t)}{\rho - g_L + I} = w_N a_N X(t). \tag{29}$$

The LHS of (29) represents the expected gain from R&D that is equal to the present value of expected profits discounted by the interest rate, the capital gain, and the hazard rate of monopolistic rent from another firm's innovation. The RHS of (29) then represents the cost of R&D.

The Northern wage (compared with the Southern wage), which affects the cost of R&D, is determined by the condition on FDI. When production is carried out in both countries continuously, $\dot{v}_N(t)/v_N(t) = \dot{v}_F(t)/v_F(t)$ must be satisfied because (18) holds at each time point. Therefore, from (19) and (20), the profits of a Northern leader firm and a multinational firm must satisfy $\pi_N(t) = (1-m)\pi_F(t)$ in equilibrium. Substituting (9), (14), and (27) into this equation, we obtain the Northern wage as a decreasing function of n_S:

$$w_N = \tau_N(1-m)(\lambda-1) + \frac{1+\tau_N(1-n_S)}{1+\tau_S n_S}(1-m+m\lambda). \tag{30}$$

The reason the Northern wage is decreasing with n_S can be explained as follows. For both a Northern leader firm and a multinational firm, profits per unit of consumption expenditure in the local market (the North for a Northern leader firm and the South for a multinational firm) are higher than those in the other market because firms can differentiate their prices in the two markets.[13] As shown in (27), an increase in n_S raises the share of Southern aggregate expenditure to world aggregate expenditure, $1-\phi$, and therefore, increases the profits of a multinational firm compared with a Northern leader firm. Because this increases the incentive for a production transfer to the South, the Northern wage must decline so that the incentive for production in the North can increase.

Combining (25) and (29), we have the following equation:

$$\frac{\frac{(1-m)(\lambda-1)}{1-m+m\lambda}\frac{L_S(t)}{X(t)}}{\rho-g_L+I}=n_S w_N a_N. \tag{31}$$

From (30), the RHS of (31) is increasing with n_S and tends to zero as $n_S \to 0$.[14] Therefore, the relation between n_S and I satisfying (30) and (31) is negative and asymptotes to the vertical axis, as depicted in Figure 1. We refer to this as the *R&D curve*, which shows the combinations of n_S and I that are consistent with an incentive to carry out R&D.

The R&D curve is downward sloping because the innovation rate I consistent with an incentive for R&D decreases with n_S. In the Southern labor market, an increase in n_S pushes up the Southern wage when compared with world aggregate expenditure, $1/E(t)$. This decreases the demand for multinational firms' goods through increasing their prices compared with aggregate expenditure. As a result, it decreases the profits of multinational firms and thereby the expected gain by R&D. This effect appears as n_S on the RHS of (31). Meanwhile, an increase in n_S also reduces the cost of R&D through lowering the Northern wage w_N, as shown by (30). However, the decrease in the expected gain necessarily dominates the decrease in the cost. Therefore, as n_S increases, I must be lower in terms of the incentive for R&D.

The intersection of the LC and R&D curves provides the equilibrium values of n_S and I. As depicted in Figure 1, the LC and R&D curves intersect only once if the R&D curve lies below the LC curve around the upper limit of n_S.[15] Then, there exists a unique interior equilibrium such that n_S and I are positive. Depending on the equilibrium value of n_S, (25), (27), and (30) determine the equilibrium values of $E(t)$, ϕ, and w_N, respectively.

13. Equations (6), (8), (11), and (13) show that the profits per unit of consumption expenditure of a Northern leader firm are $1-w_N(t)/[\lambda(1+\tau_N)]$ in the North and $1/(1+\tau_S)-w_N(t)/\lambda$ in the South, while those of a multinational firm are $(1-1/\lambda)/(1+\tau_N)$ in the North and $1-1/\lambda$ in the South.

14. For the proof that the RHS is increasing with n_S, see Appendix E in the Supporting Information.

15. This condition can be expressed by $L_N(t)/[a_N X(t)]-g_L+\rho>[(1+\tau_S)(1-m)(\lambda-1)L_S(t)]/\{(1-m+m\lambda)a_N X(t)[(1+\tau_S)\tau_N(1-m)(\lambda-1)+(1-m+m\lambda)]\}$, or equivalently, $f(1)>h(1)$, where the definitions of $f(\cdot)$ and $h(\cdot)$ are given in the proof of Proposition 3. This condition is satisfied when the quantity of labor supplied in the North is sufficiently large and/or that in the South is sufficiently small.

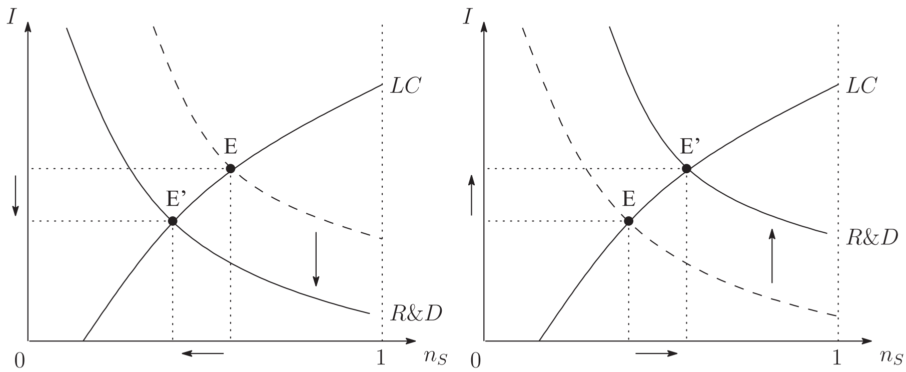

Fig 2. The Effects of a Unilateral Tariff Increase.

3. COMPARATIVE STATICS

In this section, we conduct comparative statics using Figure 1.

3.1 A Unilateral Tariff Increase

We first consider the effects of a unilateral tariff increase by the North. Given n_S, an increase in τ_N raises w_N, as shown in (30). This is because the Northern tariff affects the incentive for FDI. For Northern leader firms, an increase in τ_N reduces competition pressure in the Northern market because it raises the lowest price that the follower firms in the South could charge after the tariff. This enables the Northern leader firms to raise the price in the Northern market, which increases their profits. Meanwhile, the higher Northern tariff pushes up the duty-inclusive price of goods produced by multinational firms. This reduces the demand for the goods and consequently, the profits of multinational firms. Because the increased profits of a Northern leader firm and the decreased profits of a multinational firm decrease the incentive for FDI, the relative wage of Northern to Southern labor must increase to restore equilibrium.

Since the higher Northern wage leads to a higher cost of R&D, an increase in τ_N negatively affects the incentive for R&D and the innovation rate I for a given n_S from the R&D equilibrium condition (31). This means that an increase in τ_N shifts the R&D curve downward. However, the LC curve (28) does not change because the tariff increase affects the labor inputs of the Northern leader firms, the multinational firms, and imitators proportionately, as shown in (24) and (25). As a result, an increased Northern tariff lowers both n_S and I, as in Figure 2(a). In addition, from (30), it raises the relative wage of Northern labor to Southern labor through both the direct effect discussed above and an indirect effect through the decrease in n_S. These results are summarized as follows.

PROPOSITION 1. *A unilateral tariff increase by the North reduces innovation and FDI from the North to the South, although it also raises the relative wage of Northern to Southern labor.*

Next, we analyze the effects of a unilateral tariff increase by the South. As the Southern tariff increases, the Northern leader firms need to lower their pretariff export prices to the South, p_{NS}. Given n_S, this reduces the Northern leaders' profits, and consequently, increases the incentive for FDI. As shown in (30), the Northern wage w_N must decrease to restore equilibrium as τ_S increases. Because the decreased Northern wage reduces the cost of R&D, a higher τ_S positively affects the incentive for R&D and innovation rate I for a given n_S from the R&D equilibrium condition (31). Therefore, the R&D curve shifts upward. However, the LC curve does not change because an increase in τ_S does not affect the labor input for production. As a result, a tariff increase by the South increases both n_S and I, as in Figure 2(b). In addition, equation (30) shows that it reduces w_N through both the direct effect and the indirect effect through the increase in n_S.

PROPOSITION 2. *A unilateral tariff increase by the South promotes innovation and FDI from the North to the South. Moreover, it raises the relative wage of Southern to Northern labor.*

With a North–South innovation–imitation model not including FDI, Grieben and Şener (2009) concluded that a unilateral reduction of the Southern (Northern) import tariff has no effect on innovation in their basic model but decreases (increases) the innovation rate in their extended model with a perfectly competitive low-tech sector in the South. Our results for Propositions 1 and 2 on innovation are similar to those of their latter model, but differ from those of their former model.

3.2 Tariff Increases by Both Countries

In the former section, we concluded that a tariff increase by the South promotes innovation and FDI. Nevertheless, this does not necessarily imply that such a policy change is favorable. This is because a tariff increase by the South may result in a retaliatory tariff by the North, which has a negative effect on innovation and FDI. Next, we discuss the effects of simultaneous tariff increases by the North and South. In Section 3.2, we assume that the initial tariff rate in the North is not higher than that in the South; that is, $\tau_N = \tau$ and $\tau_S = \tau + \bar{\tau}$ where $\tau \geq 0$ and $\bar{\tau} \geq 0$.[16] Under this setting, we analyze the effects of an increase in τ.

We interpret the effects of tariff increases by both countries as the combined effects of unilateral tariff increases by the North and South. Similar to a unilateral tariff increase, neither the Northern nor Southern tariffs affect the LC curve from (28). Meanwhile, (31) shows that the tariff increases by both countries affect the R&D

16. In fact, according to the World Bank Open Data (https://data.worldbank.org/), the weighted mean tariff rate applied in 2017 was 4.28% in "low & middle income" countries, which was higher than 2.02% in "high income" countries.

curve only through the change in w_N. If an increase in τ raises w_N for a given value of n_S, it moves the R&D curve downward and vice versa. Partially differentiating (30) with respect to τ, we have

$$\left.\frac{\partial w_N}{\partial \tau}\right|_{n_S=\text{given}} = \frac{\lambda - 2n_S[(1-m+m\lambda)-(1-m)(\lambda-1)\tau_S]}{(1+\tau_S n_S)^2} + \frac{(1-m)(\lambda-1)\tau_S^2 n_S^2 + (\tau_S-\tau_N)(1-m+m\lambda)n_S(1-n_S)}{(1+\tau_S n_S)^2}. \tag{32}$$

This equation shows that given n_S, an increase in τ raises w_N if (i) $\tau_S \geq (1-m+m\lambda)/[(1-m)(\lambda-1)]$ or (ii) $\tau_S < (1-m+m\lambda)/[(1-m)(\lambda-1)]$ and $n_S < \lambda/\{2[(1-m+m\lambda)-(1-m)(\lambda-1)\tau_S]\} \equiv \hat{n}_S$. Consequently, if the R&D and LC curves intersect at a value of n_S lower than $\hat{n}_S$, an increase in τ moves the R&D curve downward around the intersection of the two curves, and the equilibrium to the lower left along the LC curve. This implies, in that case, that simultaneous tariff increases by both countries reduce the equilibrium values of I and n_S. This is the case if the following condition is satisfied.

PROPOSITION 3. *Suppose that the initial tariff rate in the North is not higher than that in the South: $\tau_N \leq \tau_S$. Then, simultaneous tariff increases by the North and South to the same degree reduce innovation and FDI if $L_N(t)/[a_N X(t)] + \rho - g_L > L_S(t)/[(1-m+m\lambda)a_N X(t)]$.*

PROOF. See Appendix A in the Supporting Information. □

Proposition 3 implies that the tariff increases by both countries tend to be detrimental to innovation and FDI if the share of population size is large in the North and small in the South. In such a case, the negative effects of an increase in the Northern tariff tend to dominate the positive effects of an increase in the Southern tariff. However, the negative effects on innovation and FDI are quantitatively smaller than for a unilateral tariff increase by the North. This is because the increase in the Southern tariff works toward alleviating the negative effects.

Using the proof of Proposition 3, we also have the following result.

COROLLARY. *Suppose that the initial tariff rate is zero in the North and South: $\tau_N = \tau_S = 0$. Then, simultaneous tariff increases by the North and South to the same degree reduce innovation and FDI if and only if $L_N(t)/[a_N X(t)] + \rho - g_L > L_S(t)/[(1-m+m\lambda)a_N X(t)]$.*

PROOF. See Appendix A in the Supporting Information. □

Unlike Proposition 3, the condition in this corollary is necessary and sufficient for the result. This implies a symmetric tariff rate between the two countries that maximizes innovation and FDI is not zero, but strictly positive if the condition is not satisfied. Furthermore, the condition is more restrictive when m is small through strong IPR protection in the South. This is because a smaller m results in a larger equilibrium value of n_S, as discussed in Section 3.3. As n_S is large, the simultaneous tariff increases by both countries tend to reduce w_N from (32) and move the R&D curve upward around the equilibrium, which increases innovation and FDI.

3.3 *A Change in IPR Protection in the South*

Next, we analyze how the imitation rate m influences innovation and FDI to consider the effects of strengthening IPR protection in the South.

Equation (28) shows that a decrease in m rotates the LC curve counterclockwise around the point $(1, L_N(t)/a_N X(t))$ on the n_S-I plane. Given n_S, a lower imitation rate decreases the number of imitated goods with larger production volumes, and thus decreases labor demand in the South. The smaller labor demand lowers the wage of the South compared with the world aggregate expenditure, $1/E(t)$, in the Southern labor market. Because this pushes down the marginal cost of follower firms if they produce in the South, the Northern leader firms set a lower price and expand production, which increases labor demand in the North. As a result, for a given value of n_S, a lower imitation rate decreases the quantity of labor available for R&D in the North and negatively affects the innovation rate I.

Equations (30) and (31) imply that a decrease in m shifts the R&D curve upward for two reasons. First, a lower imitation rate increases the return from successful R&D. This is because it increases the expected profits of a multinational firm through (i) raising the probability of earning profits and (ii) reducing the marginal cost of production (the wage of the South) compared with the world aggregate expenditure $1/E(t)$. Second, a lower imitation rate has a negative effect on the Northern wage w_N and thereby the cost of R&D. This is because it stimulates production transfer to the South through increasing the expected profits of a multinational firm. Partially differentiating (30) with respect to m verifies this effect:

$$\left.\frac{\partial w_N}{\partial m}\right|_{n_S=\text{given}} = (\lambda - 1)\left[-\tau_N + \frac{1+\tau_N(1-n_S)}{1+\tau_S n_S}\right] \geq 0, \tag{33}$$

where the inequality holds because $\tau_N \leq 1/(1+\tau_S n_S)$ must be satisfied to ensure nonnegative profits of Northern leader firms in the Southern market, as shown in Appendix A in the Supporting Information. Through the abovementioned two effects, a lower m positively affects the incentive for R&D and the innovation rate I for a given value of n_S. In equation (31), the first effect is represented by a decrease in m on the LHS, while the second effect is represented by a decrease in w_N on the RHS, both of which show that a lower m must increase I, given n_S.

Figure 3 depicts the effects of a decrease in m on the equilibrium. The intersection of the LC and R&D curves moves from point E to point E'. Figure 3 shows that a lower m unambiguously increases the equilibrium value of n_S. Because (30) shows that w_N is decreasing with n_S, a decreased m lowers w_N through both the direct effect represented by (33) and the indirect effect by the increase in n_S. Meanwhile, Figure 3 does not indicate whether a lower m increases the equilibrium value of I because it includes both the negative effect through tightening the labor constraint in the North

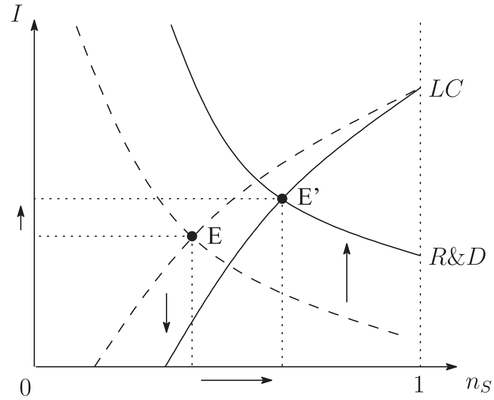

Fig 3. The Effects of a Decrease in the Imitation Rate.

and the positive effect through improving the incentive for R&D. On this point, we conclude as follows using total differentiation.

PROPOSITION 4. *A decrease in the imitation rate through strengthening IPR protection in the South (i) promotes innovation, (ii) increases FDI, and (iii) decreases the relative wage of Northern to Southern labor.*

PROOF. See Appendix A in the Supporting Information. □

Note that Proposition 4 holds regardless of whether the tariff in both countries is zero or positive, and implies that tariffs do not qualitatively change the effects of strengthening IPR protection in the South on innovation and FDI. In addition, the result for Proposition 4 is consistent with those for Gustafsson and Segerstrom (2011), Lai (1998), and Tanaka and Iwaisako (2014) using North–South innovation–FDI models with exogenous imitation not including tariffs.

4. WELFARE ANALYSIS

In this section, we examine how unilateral tariff increases by the North and South impact their own welfare. To this end, we first derive the utility of a household in each country. From (1), the instantaneous utility can be decomposed into two parts, utility from quality and utility from quantity, as follows:

$$\log u_i(t) = \int_0^1 \log \lambda^{J(\omega,t)} d\omega + \int_0^1 \log d_i(J(\omega,t),\omega,t)d\omega, \tag{34}$$

where $J(\omega, t)$ is the generation number of the state-of-the-art quality of good ω available at time t. Hereinafter, we let $\log Q(t)$ and $\log D_i$ denote the first and second terms of (34), respectively. Substituting (3) and the prices into $\log D_i$ yields the utility from quantity as follows:

$$\log D_N = n_N \log \frac{E_N}{\lambda(1+\tau_N)} + (1-m)n_S \log \frac{E_N}{\lambda(1+\tau_N)} + mn_S \log \frac{E_N}{1+\tau_N}$$
$$= \log E_N - \log(1+\tau_N) - (1-mn_S)\log\lambda, \quad (35)$$

$$\log D_S = n_N \log \frac{E_S}{\lambda} + (1-m)n_S \log \frac{E_S}{\lambda} + mn_S \log E_S = \log E_S - (1-mn_S)\log\lambda (36)$$

By rewriting (22), the Northern expenditure in (35) is expressed as

$$E_N = (1+\tau_N)\frac{L_S(t)}{L_N(t)}\left(\frac{\lambda}{1-m+m\lambda}\frac{1}{n_S} - E_S\right). \quad (37)$$

The Southern expenditure in (36) and (37) is derived from (26) as follows:

$$E_S = \frac{1}{1-n_N\frac{\tau_S}{1+\tau_S}} = \frac{1+\tau_S}{1+\tau_S n_S}. \quad (38)$$

Meanwhile, the growth rate of $Q(t)$ is given by $d\log Q(t)/dt = I\log\lambda$. Substituting this into (34), we have the lifetime utility of a household in country i as

$$U_i = \int_0^\infty e^{-(\rho-g_L)t}(It\log\lambda + \log D_i)dt = \frac{1}{\rho-g_L}\left(\frac{I\log\lambda}{\rho-g_L} + \log D_i\right),$$

where $\log D_i$ is given by (35)–(38) and we use $\log Q(0) = 0$ from the normalization of the generation number. From this lifetime utility, we next derive the welfare change by a tariff increase in each country.

4.1 Welfare Effect of a Northern Tariff Increase

By differentiating the Northern household's lifetime utility with respect to τ_N, we obtain the Northern welfare change from a marginal increase in its tariff rate as follows:

$$\frac{\partial U_N}{\partial \tau_N} = \frac{1}{\rho-g_L}\left[\underbrace{\frac{\log\lambda}{\rho-g_L}\frac{\partial I}{\partial \tau_N}}_{\substack{\text{innovation-}\\ \text{impeding}\\ \text{effect}\\ (-)}} + \underbrace{\frac{1}{E_N}\frac{\partial E_N}{\partial \tau_N}}_{\substack{\text{income}\\ \text{effect}\\ (+)}} \underbrace{-\frac{1}{1+\tau_N}}_{\substack{\text{price-}\\ \text{raising}\\ \text{effect}\\ (-)}} \underbrace{+m(\log\lambda)\frac{\partial n_S}{\partial \tau_N}}_{\substack{\text{competition-}\\ \text{weakening}\\ \text{effect}\\ (-)}}\right]. \quad (39)$$

Equation (39) shows that the total welfare effect of a Northern tariff increase (an increase in τ_N) can be decomposed into the following four parts. First, the increased Northern tariff impedes innovation, as shown in Proposition 1, and thus reduces welfare. We refer to this welfare effect as the *innovation-impeding effect*. Second, the increased Northern tariff increases Northern income, as we later demonstrate. We refer to this welfare effect as the *income effect*. Third, the Northern tariff increase raises prices in the North and thus reduces welfare. We refer to this welfare effect as the *price-raising effect*. Finally, the Northern tariff increase impedes FDI and consequently decreases the number of goods produced by the Southern imitators mn_S. The price of the imitated goods is lower than that of the goods produced by Northern and multinational firms, so that a decrease in the number of imitated goods reduces welfare. We refer to this welfare effect as the *competition-weakening effect*.

The sum of the income effect and price-raising effect is equal to $\frac{1}{\rho-g_L}\frac{1+\tau_N}{E_N}\frac{\partial\frac{E_N}{1+\tau_N}}{\partial\tau_N}$. From (37) and (38), differentiating $E_N/(1+\tau_N)$ with respect to τ_N yields

$$\frac{\partial\frac{E_N}{1+\tau_N}}{\partial\tau_N} = \frac{L_S(t)}{L_N(t)}\left[-\frac{\lambda}{1-m+m\lambda} + (E_S n_S)^2\frac{\tau_S}{1+\tau_S}\right]\frac{1}{{n_S}^2}\frac{\partial n_S}{\partial\tau_N} > 0, \tag{40}$$

where the inequality holds because $\lambda/(1-m+m\lambda) > 1$, $E_S n_S = (1+\tau_S)n_S/(1+\tau_S n_S) < 1$, and $\partial n_S/\partial\tau_N < 0$ from Proposition 1. As the price-raising effect is necessarily negative, this means that the income effect is necessarily positive. This is because the increased Northern tariff raises the Northern tariff revenue, the Northern wage, as shown in Proposition 1, and the value of the holding stocks proportionate to the Northern wage from (17) and (18).

Although both negative and positive welfare effects exist, the total welfare effect is negative under a certain parameter condition because the sum of the innovation-impeding and price-raising effects surpasses the positive income effect. This result is summarized as follows.

PROPOSITION 5. *If* $\frac{\log\lambda}{\rho-g_L}\left[\frac{L_N(t)}{a_N X(t)} + \rho - g_L\right] > \frac{\lambda}{1-m+m\lambda}(1+\tau_S)$, *a unilateral tariff increase by the North worsens the North's welfare.*

PROOF. See Appendix A in the Supporting Information. □

Note that the condition in Proposition 5 does not depend on the value of τ_N. This implies that the welfare-maximizing tariff rate for the North is zero if the condition is satisfied.

From the condition in Proposition 5, the welfare effect tends to be negative when Northern labor is larger, the imitation rate in the South is higher, and the Southern tariff rate is lower. A tariff increase by the North has a positive effect on the North's welfare because it shifts production from the South to the North and raises the Northern wage. However, this positive welfare effect is weak under large Northern labor, a high imitation rate in the South, and a low Southern tariff rate because the number of industries producing in the South is smaller in these cases. That is why the total welfare effects of the Northern tariff tend to be negative.

4.2 Welfare Effect of a Southern Tariff Increase

Next, by differentiating the Southern household's lifetime utility with respect to τ_S, we obtain the Southern welfare change from a marginal increase in its tariff rate as follows:

$$\frac{\partial U_S}{\partial \tau_S} = \frac{1}{\rho - g_L}\left[\underbrace{\frac{\log\lambda}{\rho - g_L}\frac{\partial I}{\partial \tau_S}}_{\substack{\text{innovation-}\\\text{enhancing}\\\text{effect}\\(+)}} + \underbrace{\frac{1}{E_S}\frac{\partial E_S}{\partial \tau_S}}_{\substack{\text{income effect}\\(+)\text{ or }(-)}} + \underbrace{m(\log\lambda)\frac{\partial n_S}{\partial \tau_S}}_{\substack{\text{competition-}\\\text{strengthening}\\\text{effect}\\(+)}}\right]. \tag{41}$$

Equation (41) shows that the total welfare effect of a Southern tariff increase (an increase in τ_S) can be decomposed into the following three parts. First, the Southern tariff increase enhances innovation, as shown in Proposition 2, and thus raises welfare. We refer to this welfare effect as the *innovation-enhancing effect*. Second, the Southern tariff increase may increase or decrease Southern expenditure because it affects the transfer payment from the tariff revenue of the Southern government. We refer to this effect as the *income effect*.[17] Finally, the Southern tariff increase promotes FDI and increases the number of the goods produced by Southern imitators mn_S. The increase in imitated goods improves welfare because they are cheaper than the goods produced by Northern leaders and multinationals. We refer to this welfare effect as the *competition-strengthening effect*.

As shown in Appendix A in the Supporting Information, under a certain parameter condition, the positive welfare effects surpass the negative part of the income effect, which is the negative effect on the tariff revenue from the decrease in the number of the goods produced in the North. Accordingly, the total welfare effect of an increase in the Southern tariff is positive in that case, as in the following proposition.

PROPOSITION 6. *If* $\frac{\log\lambda}{\rho - g_L}\frac{L_S(t)}{(1-m+m\lambda)a_N X(t)} + m\log\lambda + \left[\frac{\log\lambda}{\rho - g_L}\frac{L_S(t)}{(1-m+m\lambda)a_N X(t)} - 1\right]\tau_S > 0$*, a unilateral tariff increase by the South improves the South's welfare.*

PROOF. See Appendix A in the Supporting Information. □

Note that the condition in Proposition 6 is necessarily satisfied if τ_S is zero. This implies that the welfare-maximizing tariff rate for the South is strictly positive. Thus,

17. From equation (38), a higher Southern tariff increases tariff revenue of the South, and thus has a positive effect on Southern income if and only if the elasticity of n_N with respect to τ_S is lower than $1/(1+\tau_S)$. Differentiating (38) with respect to τ_S, we have $\frac{\partial E_S}{\partial \tau_S} = \frac{(E_S)^2 n_N}{1+\tau_S}\left[\frac{1}{1+\tau_S} - \left(-\frac{\tau_S}{n_N}\frac{\partial n_N}{\partial \tau_S}\right)\right]$. Therefore, $\partial E_S/\partial \tau_S > 0$ if and only if $-(\tau_S/n_N)(\partial n_N/\partial \tau_S) < 1/(1+\tau_S)$.

the result shows that, in contrast to the North, the South has a stronger incentive to raise tariffs.

The results of the welfare analysis in this section have implications for the optimal tariff literature. Many theoretical studies have concluded that larger countries tend to set higher tariffs, but the opposite is actually observed.[18] As discussed, our model shows that the optimal tariff for the North may be zero, whereas that for the South is necessarily positive. The difference is due to the dissimilar effects of tariffs in the two countries on innovation, FDI, and prices. In contrast to extant theoretical studies, our welfare analysis can then explain the observation that larger countries tend to set lower tariffs.

4.3 Numerical Examples

As we can surmise from the results of Propositions 5 and 6, under a certain condition, the optimal tariff rate for the North is zero, whereas the optimal tariff rate for the South is positive. To show this explicitly, we provide numerical examples.

We set the parameters as follows. We consider the U.S. and China to represent the North and the South, respectively. According to the indicators of the World Bank, the total labor forces of the U.S. and China are about 165 million and 792 million, respectively. Thus, we set the ratio of the Southern labor to the Northern labor to 4.8. Table XI of Jordà et al. (2019) shows that the average rate of return of safe assets in the U.S. has been about 3.9% since the 1980s, and thus we set $\rho = 0.039$. As in Jones and Williams (2000), we set the population growth rate g_L to 1.44%, which corresponds to the long-run growth rate of the U.S. labor force. Basu (1996) estimated that the mark-up belongs in the interval [1.1,1.4], and we choose $\lambda = 1.4$. To guarantee that n_S is less than one, we set the imitation rate to $m = 1/3$. Finally, we set the ratio of R&D cost to the Northern labor $a_N X(t)/L_N(t)$ to 13 so that the growth rate of output is close to 1.8%, which is the average growth rate of the U.S.

Next, we need to derive the domain of the tariff rates that satisfy the conditions that we assume so far. From Appendix F in the Supporting Information, the tariff rates need to satisfy two conditions. First, the tariff rates need to satisfy $1 + \lambda\tau_N < w_N(t)$, which guarantees that FDI firms do not choose local production in the North to avoid tariffs. Under the above parameter values, the domain of the tariff rates that satisfies the first condition is given by the region that is below the solid line in Panel

18. There are a few exceptions. Naito (2019) obtained a result consistent with the actual tendency using a two-country growth model. However, the engine of growth in that model is not R&D, but capital accumulation, nor is it a North–South model. More recently, Naito (2021) and Beladi et al. (2022) examined the optimal tariffs in a two-country R&D-based growth model. Beladi et al. considered the situation where government spending financed by tariff revenue raises the productivity of the country. They showed that even though the Nash equilibrium tariff rate is positive, a larger country tends to have a lower optimal tariff. Naito (2021) demonstrated that the optimal tariff for a large country can even be zero. Our work complements these studies in two respects. First, their models are variety-expansion models whereas ours is a quality-improvement model. Second, their models are North–North models where neither FDI nor imitation is incorporated, unlike our model. One of the contributions of our study is then to show that developing countries that are the recipients of FDI have stronger incentives to impose an import tariff than developed countries that are innovative using a North–South model.

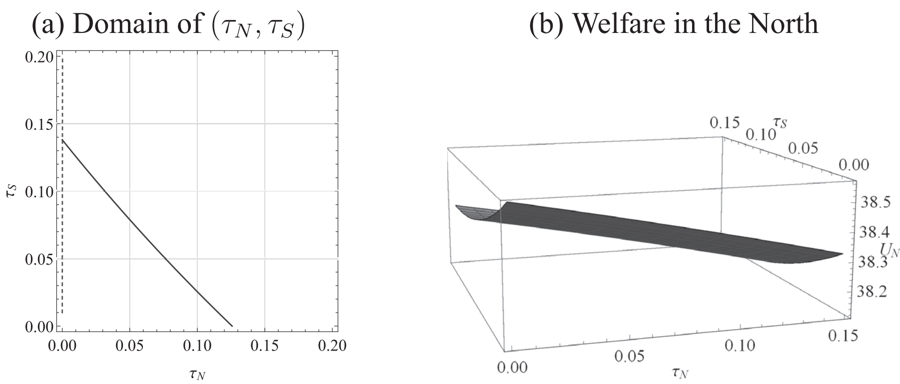

Fig 4. The Case Where the Optimal Northern Tariff Is Zero and the Optimal Southern Tariff Is Positive.

(a) of Figure 4. Second, the tariff rates need to satisfy $w_N(t) < \lambda/(1 + \tau_S)$, which guarantees that Northern leader firms supply the goods in the South. Under the above parameter values, the region that satisfies the second condition is wider than the region that satisfies the first condition. Thus, we obtain the domain of the tariff rates as in Panel (a) of Figure 4.

Given the above parameter values, the condition in Proposition 6 holds, that is, an increase in the Southern tariff necessarily raises the Southern welfare. Given the Northern tariff rate, the optimal response tariff rate of the South is the tariff rate that is as high as possible, and therefore the corner of the domain, that is, the solid line in Panel (a) of Figure 4.[19] By contrast, the Northern welfare is a decreasing function of the Northern tariff, as in Panel (b) of Figure 4. Thus, the optimal response tariff rate of the North given the Southern tariff rate is zero and is shown by the dotted line in Panel (a). Hence the Nash equilibrium tariff combination in the domain is the intersection of the two lines in Panel (a), that is, the combination of the zero tariff rate in the North and the positive tariff rate in the South.[20]

5. CONCLUDING REMARKS

Using a North–South quality ladder model, this paper investigated how import tariffs affect innovation, FDI, and welfare under imperfect IPR protection in a developing country. The conclusion is that a unilateral tariff increase by a developed country

19. Strictly, the domain of tariffs does not include the solid line and thus the optimal response of the Southern tariff is not the solid line but infinitesimally below the line.

20. For the case where the optimal Northern tariff is positive, see Appendix G in the Supporting Information.

reduces innovation and FDI, whereas that by a developing country promotes innovation and FDI. In addition, because of the decrease in innovation, a unilateral tariff increase by the developed country tends to worsen its welfare if the country is large, the tariff rate of the developing country is low, and the protection of IPR in the developing country is weak. By contrast, a unilateral tariff increase by the developing country improves its welfare if the initial tariff rate is sufficiently low, which implies that the optimal tariff rate for the developing country is positive.

Possible directions for further research include extensions to address the following issues. First, we assumed that the process of FDI is costless for analytical tractability. This could be justified if production startup costs are small or similar between the two countries. However, it would be useful to examine whether our results continue to hold, even with the cost of FDI. Second, we assumed harmonization in the patent system, such as breadth of coverage, between the developed and developing countries. To investigate the effects of tariffs when the breadth of patent coverage differs between the two countries would also be interesting.[21] Third, we did not consider the differences between skilled and unskilled labor. However, in the real world, the R&D sector is likely to require more skilled labor than the production sector. To examine how a tariff increase affects innovation, FDI, and wage gap in such a setup would also be important. Moreover, we could explore how increases in skilled and unskilled labor affect innovation and skill premium, as in Chu, Cozzi, and Furukawa (2015), or endogenize skill acquisition, as in Dinopoulos and Segerstrom (1999a) and Cozzi and Impullitti (2010). Finally, we ruled out R&D activities by the developing country. In fact, R&D spending has recently increased in a few emerging countries such as China. International trade between a developed country and a "developing" country that undertakes both imitation and R&D may then be an intermediate case between North–South trade and North–North trade. It may then be interesting to investigate how tariffs affect innovation and technology transfer in this case. As all of these extensions are worth examining, but beyond the scope of this paper, we defer them to future research.

APPENDIX: DYNAMICS OF THE MODEL

In this appendix, we show that this model does not have transitional dynamics. Rewriting (25) and applying $n_S(t) \equiv 1 - n_N(t)$, we obtain

$$[1 - n_N(t)]\left(\frac{\phi}{1+\tau_N} + 1 - \phi\right)\frac{E(t)}{\lambda} = \frac{L_S(t)}{1 - m + m\lambda}. \tag{A1}$$

Note that ϕ must be constant on the equilibrium path because $E_N(t)$ and $E_S(t)$ grow at the same rate from (4). Adding both sides of this equation to those of (24) and rewriting, we have the following equilibrium innovation rate:

21. For example, Iwaisako, Tanaka, and Futagami (2011) examined how extending patent breadth in the South affects innovation and FDI with no tariff.

$$I(t)=\frac{L_N(t)}{a_NX(t)}+\frac{L_S(t)}{(1-m+m\lambda)a_NX(t)}-\frac{1}{a_N\lambda}\left(\frac{\phi}{1+\tau_N}+1-\phi\right)\frac{E(t)}{X(t)}. \quad \text{(A2)}$$

For both a Northern leader firm and a multinational firm to exist at each time point, (18) must be satisfied over time. Differentiating both sides of (18) with respect to t yields $\dot{v}_N(t)=\dot{v}_F(t)$. Substituting this and (18) into (19) and (20), we have $\pi_N(t)=(1-m)\pi_F(t)$. Therefore, from this equation, (9), (14), and the definition of ϕ, we obtain

$$w_N(t)=\frac{\lambda\left(\phi+\frac{1-\phi}{1+\tau_S}\right)}{\frac{\phi}{1+\tau_N}+(1-\phi)}-(1-m)(\lambda-1).$$

Hence, the Northern wage must be constant over time on the equilibrium path because ϕ is constant. As w_N is constant, (17) and (18) imply that $v_N(t)$ and $v_F(t)$ grow at the same rate as $X(t)$. Accordingly, from (9), (17), (19), and (A2), the equilibrium interest rate is expressed as

$$\begin{aligned}r(t)=&\frac{1}{w_Na_N}\left(\phi+\frac{1-\phi}{1+\tau_S}\right)\frac{E(t)}{X(t)}+g_L-\frac{L_N(t)}{a_NX(t)}\\&-\frac{L_S(t)}{(1-m+m\lambda)a_NX(t)}.\end{aligned} \quad \text{(A3)}$$

Next, taking the logarithm of $E(t)/X(t)$ and differentiating it with respect to t yields

$$\begin{aligned}\frac{[E(t)\dot{/}X(t)]}{E(t)/X(t)}=&\left[\frac{\dot{E}_N(t)}{E_N(t)}+\frac{\dot{L}_N(t)}{L_N(t)}\right]\frac{E_N(t)L_N(t)}{E(t)}\\&+\left[\frac{\dot{E}_S(t)}{E_S(t)}+\frac{\dot{L}_S(t)}{L_S(t)}\right]\frac{E_S(t)L_S(t)}{E(t)}-g_L=r(t)-\rho,\end{aligned} \quad \text{(A4)}$$

where we use the definition of $E(t)$ and the Euler equation (4). Substituting (A3) into (A4), we obtain

$$\begin{aligned}\frac{[E(t)\dot{/}X(t)]}{E(t)/X(t)}=&\frac{1}{w_Na_N}\left(\phi+\frac{1-\phi}{1+\tau_S}\right)\frac{E(t)}{X(t)}\\&-\frac{L_N(t)}{a_NX(t)}-\frac{L_S(t)}{(1-m+m\lambda)a_NX(t)}-(\rho-g_L).\end{aligned} \quad \text{(A5)}$$

As $\dot{X}(t)/X(t)=g_L$, $L_N(t)/X(t)$ and $L_S(t)/X(t)$ are constant. Thus, (A5) has a unique interior steady state that is unstable. In the equilibrium, $E(t)/X(t)$ must jump to this steady-state value at the initial time point and then become constant because $E(t)/X(t)$ is jumpable. Otherwise, either (A1) or (A2) would be violated at a certain finite time point. This result implies that $r(t)=\rho$ for all t from (A4). Then, $E_i(t)$ must be constant over time from the Euler equation (4). Also, (25) and (A2) show that $n_S(t)$, $n_N(t)$, and $I(t)$ must be constant over time because $E(t)$, $X(t)$, $L_N(t)$, and $L_S(t)$ grow at the same rate on the equilibrium path.

Therefore, we conclude that the equilibrium path of this model does not have a transitional process and immediately jumps to the steady state.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure 5: Domain of (τ_N, τ_S) Figure 6: Domain of (τ_N, τ_S) when w_N(t)$<$ $(1 - m)\lambda$ is not required Figure 7: The case where the optimal Northern tariff rate is positive