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Abstract

This paper develops a North-South quality-ladder model with northern innovative R&D, southern adaptive R&D and imitative R&D to analyze the effects of tariffs on innovation, technology transfer, relative wage and welfare. We find that increasing southern tariff decreases the relative wage between the North and the South permanently, increases the technology transfer rate permanently and decreases the northern innovation rate temporarily. In contrast, increasing northern tariff increases the relative wage permanently, decreases the technology transfer rate permanently and either increases or decreases the northern innovation rate, depending on the size of the North-South labor ratio. Moreover, we calibrate this model to the US-China data to perform a quantitative analysis. We find that imposing tariff in the home country yields welfare gain in itself and yields welfare loss in the foreign country. When both countries impose tariffs simultaneously, they can benefit from the welfare gains. The numerical results are consistent with the analytical policy implications.

JEL classification: O30; O33; F13; F23

Keywords: Tariffs; Technology Transfer; Innovation; Foreign Direct Investment; Product Cycles.

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1 Introduction

Former President of the United States Donald Trump accused China of its longtime unfair trade practices with the US, leading to an enormous trade deficit for many years. By penalizing China, the US launched trade war in 2018 and levied additional tariffs on more than $300 billion worth of Chinese goods, citing in Section 301 of the US Trade Act of 1974. China retaliated and struck back by imposing tariffs on the imported goods from the US. The US-China trade war continued under the new presidency of Joe Biden. However, in 2022, the Biden administration considered the pullback of Trump-era tariffs on China in an attempt to slow down the high inflation which reached 40-year peak in the United States. China welcomed this lifting tariffs policy and alleged that removing all the US additional tariffs against China would be beneficial to the two countries and the rest of the world. The economic impacts of the large-scale US-China trade war has been a controversial topic, and the two countries' actions have been compelling to the rest of the world, worrying about the disruption of the global economy. Are the tariffs harming both economies and the welfare of their citizens?

The existing literature has not adequately examined the theoretical connections between tariffs of a developed and a developing country, innovation, technology transfer, relative wage and welfare[1]. Therefore, this paper fills this gap by constructing a North-South quality-ladder Schumpeterian model with semi-endogenous growth to examine the impacts of northern and southern tariffs in both countries. *Northern quality leaders* engage in innovative R&D to develop new products with higher quality. They can choose to produce products monopolistically in the North or shift the production to the South to become *multinational firms* to take advantage of lower production costs after successful adaptive R&D. The main contribution of this model is to consider adaptive R&D as a measure of foreign direct investment (FDI)[2] to capture the costs of the process of transferring technology from the North to the South; such costs include labor training cost, technical equipment cost, license cost, etc[3]. However, due to incomplete patent protection in the South, the products of multinational firms are at the risk of being imitated by *southern imitating firms*. Grossman and Lai (2004) and Iwaisako (2013) show that the patent protection of many developing countries remain relatively low. Grossman and Lai (2004) shows that developing countries often have less patent protection as they have smaller markets and relatively less capacity for research. Iwaisako (2013) complements the result by explaining that when developing countries cannot maintain high level of public services, they prefer to have weaker

[1]See, for example, Osang and Pereira (1996), Dinopoulos and Syropoulos (1997), Naito (2006a), Felbermayr *et al.* (2013) and Akcigit *et al.* (2018).

[2]Chu *et al.* (2019) and Zheng *et al.* (2020) also feature costly technology transfer in their studies, they analyze the effects of monetary policy and intellectual property rights policy respectively in a North-South quality-ladder model.

[3]According to the data of Bureau of Economic Analysis (BEA), the global R&D expenditure of the US multinational enterprises increased by 3.2% to $420.2 billion from 2019 to 2020, in which the US parent firms accounted for $361.2 billion R&D expenditure and foreign affiliates accounted for $59.1 billion R&D expenditure. See `https://www.bea.gov/sites/default/files/2022-11/omne1122.pdf` for the details.

patent protection.

This literature is closely related to Iwaisako and Tanaka (2020). They examine how tariffs affect innovation, technology transfer and welfare in a North-South quality-ladder model. Their results show that an increase in the unilateral tariff by the North hinders innovation and technology transfer, while an increase in the unilateral tariff by the South promotes innovation and technology transfer. However, they assume that technology transfer from the North to the South is costless. As aforementioned, existing empirical evidence shows that multinational firms invest a considerable amount of expenditures on adaptive R&D as the means of international technology transfer. Therefore, this paper fills the gap of the existing literature to investigate the effects of tariffs with costly FDI. To our best knowledge, this is the first literature which explores the effects of tariffs on innovation, technology transfer and welfare in the North-South Schumpeterian model with costly FDI. In this extended dynamic general equilibrium framework, our results are summarized as follows.

One the one hand, we find that a permanent rise in southern tariff decreases the relative wage between the North and the South permanently. Furthermore, it increases the rate of technology transfer from the North to the South permanently, but it decreases the rate of innovation in the North temporarily. Intuitively, when southern tariff increases, northern quality leaders have to lower the before-tariff prices in order to maintain their competitiveness in the South. This reduces the profits of northern quality leaders. Therefore they have less incentive in doing innovative R&D but more incentive in engaging foreign direct investment to avoid the higher southern tariff. This raises the rate of technology transfer and leads to a higher demand for adaptive R&D labor and decreases the relative wage. Consequently, northern labor are reallocated from innovation to production and this reduces the rate of northern innovation temporarily under this semi-endogenous growth model setting.

On the other hand, an increase in northern tariff increases the relative wage between the North and the South permanently. Moreover, it decreases the rate of technology transfer from the North to the South permanently but it leads to a temporary higher (lower) rate of innovation in the North if the North-South labor ratio is sufficiently large (small). The strongest rivals of northern quality leaders are the followers who produce the second newest generation of the same product. The lowest tariff inclusive price of a follower equals to the marginal cost plus northern tariff if the goods are imported from the South to the North. Northern quality leaders set the lowest quality adjusted price based on the tariff inclusive price of the follower and adjust it with the quality improvement. Therefore, when northern tariff increases, they can enjoy higher profits through setting a higher price on the products with same marginal cost and thereby they have less incentive in shifting the production from the North to the South. Hence, the increase in northern tariff reduces the rate of technology transfer and reduces the demand for adaptive R&D labor, leading to an increase in the North-South relative wage. However, a higher northern tariff generates two opposing effects on the rate of innovation. Specifically, it increases the profit margin of northern quality leaders and raises their incentive for conducting innovative R&D. This leads to a reallocation of labor from production to innovation in the North (the positive effect). In contrast, a higher northern tariff decreases the rate of technology transfer from the North to the South, implying that more products are manufactured in the North, leading to a reallocation of labor from innovation to the production in the North (the negative effect). The relative labor ratio of the two countries plays a role in disambiguating the two opposing effects. We find that an increase in northern tariff yields a temporary higher (lower) rate of northern innovation if the North-South labor ratio is sufficiently large (small).

Moreover, our paper performs a quantitative analysis with several robustness checks using the US-China data and the results support our theoretical analysis. First, we find that when China increases the tariff rate by 1 percentage point, the rate of technology transfer from the United States to China increases by 1.0883% permanently and the average quality per US worker decreases by 0.5938% temporarily. In addition, an increase in the tariff rate of China leads to a reduction in the wage gap between the United States and China by 0.3561%. In addition, this leads to a welfare gain of 0.299% in China and a welfare loss of 0.1594% in the United States. The increase in the labor wage and the positive effect of the FDI attributed mostly to the welfare gain in China, while the welfare loss in the US mostly stems from the negative impact on innovation and labor wage.

Second, when the tariff rate of the United States increases by 1 percentage point, it reduces the rate of technology transfer from the United States to China by 2.5991% and increases the average quality per US worker by 1.4697% as the US-China labor ratio is sufficiently large. Moreover, the 1 percentage point increase in the US's tariff rate leads to an increase in the wage gap by 0.8827%, a welfare loss of 0.1203% in China and a welfare gain of 0.3353% in the United States. The welfare loss in China is mostly caused by the decrease in labor wage and the negative impact of FDI. The positive effects on innovation and labor wage attributed mostly to the welfare gain in the US; this result clearly shows that imposing tariff is beneficial to home country but harmful to the foreign country.

Finally, when the tariff rates of both the United States and China increase by 1 percentage point simultaneously, the rate of technology transfer decreases by 1.5666% and the average quality per US worker increases by 0.8757%. The increase in both tariff rates widens the US-China wage gap by 0.5263% and leads to a welfare gain of 0.1784% in the US and a welfare gain of 0.1782% in China. The welfare gain in the US mostly comes from the increases in wage and the level of innovation, whereas the welfare gain in China is mostly caused by the increase in the level of innovation. Our results complements Martin and Vergote (2008), they show that the welfare of both countries increase when they increase tariffs simultaneously. The above quantitative analysis can partly explain why both the United States and China prefer the non-zero tariff policy.

2 Literature Review

A large strand of literature examine the effects of tariffs on welfare and growth, and a branch of studies find a positive relationship between them. Naito (2006a) finds that a country can attain growth, revenue and welfare gains by combining consumer-price-neutral tariff and tax reform with additional rise in the consumption tax on the less distorted good. Naito (2006b) explores how the tariff and tax reform affect the welfare and government revenue of a developing country in a dynamic general equilibrium model. He finds that a positive tariff rate should be imposed even for a small open economy with no market failure. Lee (2011) shows that a higher import tariff on the consumption good in the home country enhances economic growth when the foreign country has an absolute advantage in the investment good, and it also raises the global welfare. Felbermayr *et al.* (2013) show that the Nash tariff is increasing in relative country size and the relative average productivity in a two-country Melitz model. Our study differs from these studies by incorporating adaptive R&D in the multinational firms as the measure of costly FDI. Therefore, to the best of our knowledge, we are the first paper to analyze the cross-country effects northern and southern tariffs in a North-South Schumpeterian growth model with costly FDI.

Some papers find a negative relationship between tariff and growth. Osang and Pereira (1996) study the effect of different types of tariff on growth and welfare. They show that most types of tariffs impede growth in both short-run and long-run, and all kinds of tariffs reduce welfare in the long-run. Dinopoulos and Syropoulos (1997) develop a dynamic multi-country, multi-commodity Schumpeterian growth model with trade and tariffs. They find that if the non-traded sector is less progressive than the export sector, then higher tariffs reduce the growth of that country. Beladi *et al.* (2021) show that an increase in tariff reduces the growth rate of both the home and foreign country. Despite the negative effect of tariff on growth, the Nash equilibrium tariff can be positive as tariff enhances the welfare of a country's residents. This explains why countries opt to choose non-zero tariff policy. Our model differs from the above literature by also featuring southern imitative R&D. Once multinational firms have successfully conducted adaptive R&D, they are at the risk of being imitated by the southern imitating firms.

Another strand of literature find mixed relationships between tariff on growth and welfare. Riverabatiz and Romer (1991) analyze the effect of tariff on economic growth in a two-country model, they find a U-shaped relationship between tariff and long-run growth. Grossman and Helpman (2018) find that knowledge spillovers make the innovation more productive but widen the within-country income equality between researching labor and manufacturing labor. Akcigit *et al.* (2018) show that increasing tariff unilaterally can improve domestic welfare in the short-run but generate magnificent welfare loss in the medium and long run or when the foreign country retaliates. Grieben (2005) finds that the South-originated trade liberalization enhances innovation and increases the wage gap between skilled and unskilled workers and within the skilled workers in the North. With the North-originated trade liberalization, the above-mentioned effects are reversed. Grieben and Şener (2009) demonstrate that unilateral northern tariff for high-tech goods decreases northern innovation, imitation and economic growth, while unilateral tariff has the opposite results. Our paper also finds mixed relationship between tariffs on growth and welfare but we differ in a way that it depends on which country raises tariffs. Increasing the northern tariff yields a temporary higher (lower) rate of innovation in the North if the North-South labor ratio is sufficiently large (small). Increasing the southern tariff yields a temporary lower rate of innovation in the North. When a home country increases tariff unilaterally, it increases the welfare of itself but hurt that of another country. When both countries increase tariffs simultaneously, both countries benefit from welfare gain.

This paper is also related to the studies that examine the effect of trade liberalization on growth and welfare. Young (1991) feature learning-by-doing externality in his endogenous growth model. He shows that free trade increases the growth rate of the developed countries but reduces that of the less developed countries and and the effect on welfare is ambiguous. Melitz (2003) develops a dynamic industry model with heterogeneous firms to analyze the effect of international trade on inter-firm re-allocations and welfare gain. He shows that increases in trade leads to inter-firm re-allocations towards more productive firms which contributes to a welfare gain. Impullitti and Licandro (2018) introduce heterogeneous firms and variable mark-ups in their oligopoly trade model. They show that trade liberalization increases product market competition and triggers firm selection and productivity growth. We differ from the above-mentioned papers by using different framework, we adopt a North-South quality-ladder model with semi endogenous growth to analyze the cross country effects of tariffs on growth and welfare.

Finally, the methodology and the model structure used in this literature are related to a group of literature that feature costly technology transfer and imitation in the North-South Schumpeterian growth model. Chen (2018) shows that when there is cash-in-advance constraints on innovative R&D, a reduction in the northern nominal interest rate lowers the rate of innovation in the North and the rate of technology transfer but increases the North-South wage gap and the imitation rate in the South. By contrast, if there is cash-in-advance on the adaptive (imitative) R&D, a reduction the nominal interest rate lowers (increases) the rate of innovation in the North and the rate of technology transfer but increases (reduces) the imitation rate in the South. Chu *et al.* (2019) also feature cash-in-advance, innovation and inflation in their North-South Schumpeterian model. They show that higher northern inflation leads to a temporary decrease in the northern innovation rate, a permanent decrease in the North-South wage gap and ambiguous effect on the rate of technology transfer. Higher inflation leads to a permanent decrease in the rate of technology transfer, a permanent increase in the North-South wage gap and a temporary reduction in the northern innovation rate. Zheng *et al.* (2020) find that stronger intellectual property rights protection in the South reduces the North-South wage gap permanently, increases the rate of innovation temporarily in the North and increases the rate of technology transfer from the North to the South permanently. On the other hand, stronger protection in the North increases the North-South wage gap permanently, decreases the rate of technology transfer permanently and leads to an ambiguous effects on the innovation rate in the North. The focus of the above interesting studies is not on the issue of tariffs, thus this paper contributes to this strand of literature by analyzing the effect of tariffs on innovation, technology transfer, relative wage and welfare. Apart from incorporating costly FDI into Iwaisako and Tanaka (2020)'s model, we also complements their paper by adding a quantitative analysis to quantify the effects of tariffs on economic variables.

The structure of this literature is organized as follows. Section 3 introduces the quality-ladder model with tariffs. Section 4 derives the conditions of the steady-state equilibrium and the social welfare. Section 5 analyzes the effects of tariffs on relative wage, innovation and technology transfer. Section 6 performs the numerical calibration of the model and robustness checks. Section 7 concludes the study.

3 Model

3.1 Overview

This study follows Iwaisako and Tanaka (2020) to extend the North-South quality-ladder Schumpeterian model originated from Grossman and Helpman (1991) by incorporating costly FDI and imitation. We examine the impacts of northern and southern tariffs on the rate of technology transfer, innovation, relative wage and social welfare in both countries. This model consists of two countries, the North and the South, denoted as N and S respectively. The population size in the North and the South is $L_N(t)$ and $L_S(t)$, respectively, at time t. Both population sizes grow at the same rate $g_L > 0$. Therefore, the global labor force at time t is $L(t) = L_N(t) + L_S(t)$. Denote $1 - s = L_N(t)/L(t)$ as the share of northern labor force to the global labor force and $s = L_S(t)/L(t)$ as the share of southern labor force to the global labor force. The wage of the northern labor is $w_N(t)$ and we normalize the southern labor wage to be $w_S(t) = 1$.

The differentiated good $\omega \in [0, 1]$ is either produced in the North or in the South. Labor is the only factor of production, and one unit of labor produces one unit of good ω. The quality of generation j of good ω is $q(j, \omega) = \lambda^j$, where $\lambda > 1$ is the rate of quality increment between any two consecutive generations, therefore the quality of the newest generation j is higher than the second newest generation $j - 1$ by λ times. New entrants can enter the market with one-step higher generation of good ω. Goods are mobile across countries but labor is immobile.

We assume that both countries impose an ad valorem tariff $\tau_i(t) > 0$, $i \in \{N, S\}$ on all the imports. The governments run a balanced budget at each time t and distribute all the tariff revenues to households through lump-sum transfer.

Given that adaptive R&D is successful, production only shifts from the North to the South when multinational firms have lower marginal costs than northern quality leaders i.e.

$w_N(t) > w_S(t)$. Moreover, production only shifts back from the South to the North when northern quality leaders have successfully innovated higher quality products. Taking into account the size of quality improvement, this condition $w_S(t) > w_N(t)/\lambda$ has to hold. We follow Dinopoulos and Segerstrom (2006) to solve the steady-state equilibrium where both inequalities hold so that the relative wage between the North and the South must satisfy $\lambda > w_N(t)/w_S(t)$.

3.2 Households

Each household in country $i \in \{N, S\}$ maximizes the lifetime utility

$$U_i = \int_0^\infty e^{-(\rho - g_L)t} \log u_i(t) dt, \tag{1}$$

where $\rho > g_L$ is the subjective discount rate. Instantaneous utility function at time t is defined as

$$\log u_i(t) = \int_0^1 \log \left[\sum_j q(j,\omega) d_i(j,\omega,t) \right] d\omega, \tag{2}$$

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

$$\int_0^\infty e^{-\int_0^t r(s)ds + g_L t} E_i(t) dt = A_i(0) + \int_0^\infty e^{-\int_0^t r(s)ds + g_L t} w_i(t) dt + \int_0^\infty e^{-\int_0^t r(s)ds + g_L t} T_i(t) dt, \tag{3}$$

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

Households maximize (1) at time t by allocating per capita consumption expenditure given prices $p(j,\omega,t)$. Quality-adjusted products within each industry are perfect substitutes, so households purchase only the product with the lowest quality-adjusted price. The demand for the good with the lowest quality-adjusted price in a typical industry is given by

$$d_i(j,\omega,t) = \begin{cases} E_i(t)/p(j,\omega,t) & j = J(\omega,t), \\ 0 & \text{otherwise.} \end{cases} \tag{4}$$

Given (4), maximizing (1) subject to the standard intertemporal budget yields

$$\frac{\dot{E}(t)}{E(t)} = r(t) - \rho. \tag{5}$$

The Euler equation (5) implies that $r(t) = \rho$ in the steady state, such that consumption expenditure per capita $E_i(t)$ is constant and the consumption expenditure per capita grows over time t if and only if the interest rate exceeds the subjective discount rate.

3.3 Production

In this study, the global economy consists of the high-wage North and the low-wage South countries, and labor is the only factor used in the production sector and R&D sector. Northern firms can invest in innovative R&D to produce new, highest-quality products, and those firms are denoted as *northern quality leaders*. To take advantage of the lower production cost, northern quality leaders can transfer the production to the South to become *multinational firms* by hiring local workers to adopt the new highest-quality technology (adaptive R&D). Adaptive R&D is used as the measure of foreign direct investment and it is the cost that multinational firms have to incur so as to transfer the technology to the South. Different from Iwaisako and Tanaka (2020), the transfer of production to the South is costly in this study. After multinational firms successfully shift the production to the South, they face the risk of imitation on their products because the South has a weaker IPR protection, and firms that perform copying is referred to as *southern imitating firms*. For simplicity, we assume that the imitation rate ψ is exogenous and whether the good ω is imitated is determined independently at each time t. If the good ω is imitated at time t, southern imitating firms earn zero profit and the imitated market becomes perfectly competitive. Next, we determine the prices and demand of each good ω produced by northern quality leaders, multinational firms and southern imitating firms, respectively.

3.3.1 Northern Quality Leaders

The optimal price that a northern quality leader sets for the northern and southern markets can be different because of the tariffs. First, we determine the price that a northern quality leader charges its northern consumers. The strongest competitor against a northern quality leader is the follower firm that produces a product with one quality step below the highest-quality product. A northern follower can set the price to its marginal cost $w_N(t)$ and the follower can set the price to $w_S(t) = 1$. Therefore, the lowest possible after-tariff price of a product produced by the follower and imported to the North is $1 + \tau_N(t)$. As in Iwaisako and Tanaka (2020) we assume that $\tau_N(t)$ is low enough to satisfy $1 + \tau_N(t) < w_N(t)$.[4] The optimal after-tax price set by the northern quality leaders cannot exceed λ times of the price of the product produced by the follower, therefore $p_{NN}(t) = \lambda [1 + \tau_N(t)]$.[5] The market demand for a northern quality leader's good by the northern consumers is

$$x_{NN}(t) = \frac{E_N(t)L_N(t)}{\lambda [1 + \tau_N(t)]}. \quad (6)$$

[4] Iwaisako and Tanaka (2020) show that in equilibrium a northern quality leader does not differentiate the location of production in the North or in the South when the condition $1 + \lambda\tau_N(t) < w_N(t)$ holds. Therefore, we can assume that $1 + \tau_N(t) < w_N(t)$.

[5] As the northern quality leaders possess products with a one quality step over the strongest competitors, therefore they charge the price of the highest-quality products to be the size of the quality improvement λ times the marginal cost $1 + \tau_N(t)$ of the strongest competitors.

The northern quality leader's profit flow from selling to the northern consumers is

$$\pi_{NN}(t) = \{\lambda [1 + \tau_N(t)] - w_N(t)\} \frac{E_N(t)L_N(t)}{\lambda [1 + \tau_N(t)]}. \tag{7}$$

Similarly, we then derive the price that a northern quality leader charges to the southern consumers. A follower firm can set the lowest possible price equal to its marginal cost $w_S(t) = 1$ if it is produced in the South. Therefore, the optimal after-tariff price for a northern quality leader charges to its consumers cannot exceed λ. As the after-tariff price that the consumers pay for the products produced by the northern quality leader is $p_{NS}(t) = \lambda$, the before-tariff price is $\lambda / [1 + \tau_S(t)]$, and the demand for a northern quality leader's good by the southern consumers is

$$x_{NS}(t) = \frac{E_S(t)L_S(t)}{\lambda}. \tag{8}$$

The profit for the northern quality leader from selling to the southern consumers is

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

Combining (7) and (9), the total profit of a northern quality leader is given by

$$\pi_N(t) = \left\{ 1 - \frac{w_N(t)}{\lambda [1 + \tau_N(t)]} \right\} E_N(t)L_N(t) + \left\{ \frac{1}{1 + \tau_S(t)} - \frac{w_N(t)}{\lambda} \right\} E_S(t)L_S(t). \tag{10}$$

3.3.2 Multinational Firms

We now derive the price that a multinational firm charges its northern consumers. With the same reasoning as the northern quality leader charges its northern consumers, a multinational firm has to set the after-tariff price to be $\lambda \min \{w_N(t), 1 + \tau_N(t)\}$ so as to sell the product to the northern consumers. As we assume that $1 + \tau_N(t) < w_N(t)$, the after-tariff price is $p_{FN}(t) = \lambda [1 + \tau_N(t)]$ and the before-tariff price is λ. Therefore, the demand for a multinational firm's product by the northern consumers is

$$x_{FN}(t) = \frac{E_N(t)L_N(t)}{\lambda [1 + \tau_N(t)]}. \tag{11}$$

The profit of a multinational firm from selling the product to the northern consumers is

$$\pi_{FN}(t) = (\lambda - 1) \frac{E_N(t)L_N(t)}{\lambda [1 + \tau_N(t)]}. \tag{12}$$

Next, we derive the price that a multinational firm charges its southern consumers. If a product is produced in the South, a follower firm can set its price as low as its marginal cost $w_S(t) = 1$. Similarly, a multinational firm cannot choose a price higher than λ times of the marginal cost of a follower firm, therefore the optimal price which a multinational firm charges its southern consumers is $p_{FS}(t) = \lambda$. The demand for a multinational firm's good by southern consumers is

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

The profit of a multinational firm from selling the product to the southern consumers is

$$\pi_{FS}(t) = (\lambda - 1)\frac{E_S(t)L_S(t)}{\lambda}. \tag{14}$$

Hence, combining (12) and (14), we can obtain the total profit of a multinational firm such that

$$\pi_F(t) = \left(1 - \frac{1}{\lambda}\right)\left[\frac{E_N(t)L_N(t)}{1+\tau_N(t)} + E_S(t)L_S(t)\right]. \tag{15}$$

3.3.3 Southern Imitating Firms

A southern imitating firm sets the price of an imitated good ω to be its marginal cost $p_{MS}(t) = w_S(t) = 1$ when the good ω is imitated at time t in the South. When the imitated good is exported to the North, the after-tariff price is $p_{MN}(t) = 1 + \tau_N(t)$. The demand for an imitating firm's product by the northern consumers is

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

The demand for an imitating firm's product by the southern consumers is

$$x_{MS}(t) = E_S(t)L_S(t). \tag{17}$$

The imitating firm earns zero profits because it produces in a perfectly competitive market.

3.4 Innovative and Adaptive R&D

Innovative R&D is only performed by northern quality leaders who employ $L_{N,R}(t)$ amount of northern labor to engage in innovative R&D in industry ω. The instantaneous probability of a northern quality leader who succeeds in inventing a new highest-quality product in industry ω is given by

$$I_N(t) = \frac{Q(t)^{\xi}L_{N,R}(t)}{\beta q(t)}, \tag{18}$$

where $\beta > 0$ is an exogenous parameter, $q(t)$ captures the effect of increasing innovation complexity, removing the scale effect problem in the quality-ladder model as in Segerstrom (1998, 2000), $Q(t)^{\xi}$ represents the intertemporal knowledge spillover effect, and the parameter $\xi \in [0, 1)$

is the degree of externality. The term $Q(t)^{\xi}/[\beta q(t)]$ reflects the productivity in innovative R&D.

The expected benefit from investing in innovative R&D is $v_N(t)I_N(t)$, where $v_N(t)$ is the real value of the expected discounted profits generated by innovation and the total cost of innovative R&D is $w_N(t)L_{N,R}(t)$. Therefore, the zero-expected-profit condition of innovative R&D is

$$v_N(t)I_N(t) = w_N(t)L_{N,R}(t). \tag{19}$$

Adaptive R&D is all performed by multinational firms in the South, who employ $L_{S,R}(t)$ units of southern labor to engage in adaptive R&D in industry ω. Northern quality leader who succeeds in shifting the production to the South becomes a multinational firm with the instantaneous probability such that

$$I_F(t) = \frac{Q(t)^{\xi}L_{S,R}(t)}{\alpha q(t)}, \tag{20}$$

where $\alpha > 0$ is an exogenous parameter. Similar to the process of innovative R&D, $q(t)$ captures the effect of increasing adaptation difficulty and removes the scale effect in the adaptation process, $Q(t)^{\xi}$ represents the intertemporal knowledge spillover effect, and the parameter $\xi \in [0,1)$ is the degree of externality. The term $Q(t)^{\xi}/[\alpha q(t)]$ reflects the productivity in adaptive R&D.

The expected net benefit for a northern quality leader to invest in adaptive R&D is $v_F(t) - v_N(t)$, where $v_F(t)$ is the real value of the expected discounted profits generated by multinational firm, and the total cost of adaptive R&D is $L_{S,R}(t)$. Therefore, the zero-expected-profit condition for the adaptive R&D is

$$[v_F(t) - v_N(t)]I_F(t) = L_{S,R}(t). \tag{21}$$

As in Cozzi *et al.* (2007), we use $I_N(t) = I_N$ and $I_F(t) = I_F$ to focus on a symmetric equilibrium in this type of quality-ladder model. Finally, multinational firms face the risk of imitation with an exogenous probability $\psi > 0$.

3.5 Stock Market

The no-arbitrage condition that determines the value of $v_N(t)$ is given by

$$r(t)v_N(t) = \pi_N(t) - L_{S,R}(t) - v_N(t)I_N(t) + [v_F(t) - v_N(t)]I_F(t) + \dot{v}_N(t), \tag{22}$$

where the term on the left-hand side (LHS), $r(t)v_N(t)$, is the return on the asset $v_N(t)$, which is equal to the sum of the terms on the right-hand side (RHS) in the equilibrium. The RHS includes (i) the profit flow $\pi_N(t)$; (ii) the cost of adaptive R&D $L_{S,R}(t)$; (iii) the expected capital loss from the creative destruction $v_N(t)I_N(t)$; (iv) the expected capital gain when the adaptive R&D is successful $[v_F(t) - v_N(t)]I_F(t)$; and (v) the potential capital gain $\dot{v}_N(t)$. Using (21), the no-arbitrage condition is simplified to a familiar expression given by

$$r(t)v_N(t) = \pi_N(t) - v_N(t)I_N(t) + \dot{v}_N(t). \tag{23}$$

Similarly, the no-arbitrage condition that determines the value of $v_F(t)$ is given by

$$r(t)v_F(t) = \pi_F(t) - v_F(t)I_N(t) - v_F(t)\psi + \dot{v}_F(t), \tag{24}$$

where the term on the left-hand side (LHS), $r(t)v_F(t)$, is the return on the asset $v_F(t)$, which is equal to the sum of the terms on the right-hand side (RHS) in the equilibrium. The RHS includes (i) the profit flow $\pi_F(t)$; (ii) the expected capital loss from the creative destruction $v_F(t)I_N(t)$; (iii) the expected capital loss from imitation $v_F(t)\psi$; and (iv) the potential capital gain $\dot{v}_F(t)$.

3.6 Government Budget Constraints

The northern government imposes $\tau_N(t)$ on the imports from multinational firms and imitating firms. The sale of the goods imported by a multinational firm to the North is

$$p_{FN}(t)x_{FN}(t) = \frac{E_N L_N(t)}{1 + \tau_N(t)}. \tag{25}$$

The sale of the goods imported by a southern imitating firm to the North is

$$x_{MN}(t) = \frac{E_N(t)L_N(t)}{1 + \tau_N(t)}. \tag{26}$$

The northern government transfers all the tariff revenue to households via the lump-sum transfer per capita $T_N(t)$. Therefore, the budget constraint for the northern government at time t is given by

$$T_N(t)L_N(t) = \tau_N(t)(\theta_F + \theta_M)\frac{E_N(t)L_N(t)}{1 + \tau_N(t)}, \tag{27}$$

where θ_F and θ_M denote the proportion of goods produced by multinational firms and the proportion of goods produced by imitating firms, respectively.[6] The government imposes $\tau_S(t)$ on the imports from northern quality leaders. The sale of the goods imported by a northern quality leader to the South is

$$p_{NS}(t)x_{NS}(t) = \frac{E_S(t)L_S(t)}{1 + \tau_S(t)}. \tag{28}$$

Similarly, the government transfers all the tariff revenue to households via the lump-sum transfer per capita $T_S(t)$. Therefore, the budget constraint for the southern government at time t is given

[6] See section 4.1 for more details

by

$$T_S(t)L_S(t) = \tau_S(t)\theta_N \frac{E_S(t)L_S(t)}{1+\tau_S(t)}, \tag{29}$$

where θ_N denotes the proportion of goods produced by northern quality leaders.[7]

3.7 Decentralized equilibrium

The equilibrium is defined as a time path of prices, $\{r(t), w_N(t), w_S(t), p_{NN}(t), p_{NS}(t), p_{FN}(t), p_{FS}(t), p_{MN}(t), p_{MS}(t), v_N(t), v_F(t)\}_{t=0}^{\infty}$, a time path of allocations, $\{x_{NN}(t), x_{NS}(t), x_{FN}(t), x_{FS}(t), x_{MN}(t), x_{MS}(t), L_{N,Y}(\omega,t), L_{N,R}(\omega,t), L_{S,Y}(\omega,t), L_{S,R}(\omega,t), L_{S,M}(\omega,t)\}_{t=0}^{\infty}$, for $\omega \in [0,1]$, and a time path of tariff policy instruments $\{\tau_N(t), \tau_S(t)\}_{t=0}^{\infty}$.

Moreover, at each instance of time,

- the representative household in the North maximizes lifetime utility taking $\{r(t), p_{NN}(t), p_{FN}(t), p_{MN}(t), w_N(t)\}$ as given;
- the representative household in the South maximizes lifetime utility taking $\{r(t), p_{NS}(t), p_{FS}(t), p_{MS}(t), w_S(t)\}$ as given;
- northern quality leaders choose $p_{NN}(t)$ and $p_{NS}(t)$ to produce $x_{NN}(t)$ and $x_{NS}(t)$ respectively to maximize profits taking $w_N(t)$ as given;
- southern affiliates choose $p_{FN}(t)$ and $p_{FS}(t)$ to produce $x_{FN}(t)$ and $x_{FS}(t)$ to maximize profits taking $w_S(t)$ as given;
- northern quality leaders employ $L_{N,R}(\omega,t)$ to perform innovative R&D taking $\{r(t), w_N(t), v_N(t)\}$ as given;
- multinational firms employ $L_{S,R}(\omega,t)$ to perform adaptive R&D taking $\{r(t), w_S(t), v_F(t)\}$ as given;
- perfectly competitive southern imitating firms produce x_{MN} and x_{MS} to maximize profits taking $\{p_{MN}(t), p_{MS}(t)\}$ as given;
- both domestic and foreign markets for goods clear; and
- the labor-market-clearing conditions hold in both countries.

4 Steady-state Equilibrium

In this section, we solve the steady-state equilibrium given the northern and southern tariffs $\{\tau_N, \tau_S\}$. To do this, we first derive the steady-state number of each type of industries. Then, we derive the steady-state labor market conditions in both the North and the South. All these conditions are combined to derive the steady-state equilibrium rates of technology transfer and innovation. Finally, we derive the steady-state welfare functions of the countries.

[7] See section 4.1 for more details

First, we define the world aggregate expenditure $E(t) \equiv E_N(t)L_N(t) + E_S(t)L_S(t)$ and define $\phi \equiv E_N(t)L_N(t)/E(t)$ as the northern aggregate expenditure to world expenditure and $1-\phi$ as the southern aggregate expenditure to world aggregate expenditure, respectively. From (5), we see that ϕ becomes constant over time in the steady state because the northern expenditure $E_N(t)$ and southern expenditure $E_S(t)$ grow at the same rate.

4.1 Industry Composition

There are three types of industries in this model: northern quality leaders, multinational firms and southern imitating firms. We use $\{\theta_N, \theta_F, \theta_M\}$ to denote the steady-state measures of these three types of industries. The measures of all these industries add up to unity. Hence, the first condition to solve the steady-state measure of $\{\theta_N, \theta_F, \theta_M\}$ is

$$\theta_N + \theta_F + \theta_M = 1. \tag{30}$$

The flow into and out of each type of industry must be equal in the equilibrium. The flow into the industry θ_M is given by $\theta_F \psi$. It takes place when the technologies of multinational firms are imitated by southern imitating firms. The flow out of the industry θ_M is given by $\theta_M I_N$. It happens when southern imitating firms experience the arrival of new innovation in the North. Therefore, the second condition to solve the steady-state measure of $\{\theta_N, \theta_F, \theta_M\}$ is

$$\theta_F \psi = \theta_M I_N. \tag{31}$$

Moreover, the flow into the industry θ_F is given by $\theta_N I_F$. It takes place when northern quality leaders have successfully shifted the production to the South through adaptive R&D. The flow out of the industry θ_F is given by $\theta_F(I_N + \psi)$. It happens when multinational firms experience the arrival of new innovation in the North and when the technologies of multinational firms are imitated by southern imitating firms. Therefore, the third condition to solve the steady-state measure of $\{\theta_N, \theta_F, \theta_M\}$ is

$$\theta_N I_F = \theta_F(I_N + \psi). \tag{32}$$

Combining (30), (31) and (32) yields the steady-state of these measures such that

$$\theta_N = \frac{I_N}{I_N + I_F}, \tag{33}$$

$$\theta_F = \frac{I_N I_F}{(I_N + I_F)(I_N + \psi)}, \tag{34}$$

$$\theta_M = \frac{\psi I_F}{(I_N + I_F)(I_N + \psi)}. \tag{35}$$

4.2 Northern Labor Market

The labor-market-clearing condition in the North is given by

$$L_N(t) = L_{N,Y}(t) + L_{N,R}(t) = \int_{\theta_N(t)} L_{N,Y}(\omega, t) d\omega + \int_0^1 L_{N,R}(\omega, t) d\omega. \tag{36}$$

The amount of labor employed for production by northern quality firms is

$$L_{N,Y}(t) = \theta_N \left[\frac{E_N(t) L_N(t)}{\lambda(1+\tau_N)} + \frac{E_S(t) L_S(t)}{\lambda} \right], \tag{37}$$

and the amount of labor employed for innovative R&D is

$$L_{N,R}(t) = \beta I_N Q(t)^{1-\zeta}, \tag{38}$$

where (18) is used and the symmetry condition $I_N(t) = I_N$ is imposed. Substituting (37) and (38) into (36) yields the northern market-clearing condition in per capita terms such that

$$1 = \frac{I_N}{I_N + I_F} \frac{E(t)}{\lambda L_N(t)} \left[\frac{\phi}{(1+\tau_N)} + 1 - \phi \right] + \beta I_N X, \tag{39}$$

where $X(t) \equiv Q(t)^{1-\zeta}/L_N(t) = X$ is defined as the average quality per northern labor and is constant over time at the steady-state equilibrium.

4.3 Southern Labor Market

The labor-market-clearing condition in the South is given by

$$L_S(t) = L_{S,Y}(t) + L_{S,R}(t) + L_{S,M}(t) = \int_{\theta_F(t)} L_{S,Y}(\omega, t) d\omega + \int_{\theta_N(t)} L_{S,R}(\omega, t) d\omega + \int_{\theta_M(t)} L_{S,M}(\omega, t) d\omega. \tag{40}$$

The amount of labor employed for production by multinational firms is

$$L_{S,Y}(t) = \theta_F \left[\frac{E_N(t) L_N(t)}{\lambda(1+\tau_N)} + \frac{E_S(t) L_S(t)}{\lambda} \right]. \tag{41}$$

The amount of labor employed for adaptive R&D by multinational firms is

$$L_{S,R}(t) = \alpha \theta_N I_F Q(t)^{1-\zeta}, \tag{42}$$

where (20) is used and the symmetry condition $I_F(t) = I_F$ is imposed. The amount of labor employed for the production by southern imitating firms is given by

$$L_{S,M}(t) = \theta_M \left[\frac{E_N(t) L_N(t)}{1+\tau_N} + E_S(t) L_S(t) \right]. \tag{43}$$

Substituting (41), (42) and (43) into (40) yields the market-clearing condition in per capita terms such that

$$1 = \frac{I_F}{I_N + I_F} \left\{ \frac{E(t)}{L_S(t)} \frac{1}{I_N + \psi} \left(\frac{I_N}{\lambda} + \psi \right) \left[\frac{\phi}{(1+\tau_N)} + 1 - \phi \right] + \frac{\alpha I_N X(1-s)}{s} \right\}, \tag{44}$$

where $L_N(t)/L_S(t) = (1-s)/s$ is used.

4.4 Innovation and Technology Transfer

Differentiating the log of $X(t) \equiv Q(t)^{1-\zeta}/L_N(t)$ with respect to t yields

$$\frac{\dot{X}(t)}{X(t)} = (1-\xi) \frac{\dot{Q}(t)}{Q(t)} - \frac{\dot{L}_N(t)}{L_N(t)} = (1-\xi)(\log \lambda) I_N - g_L, \tag{45}$$

where the growth rate of $Q(t)$ is $I_N \log \lambda$. The variable $X(t)$ becomes constant in the steady-state, implying that the steady-state innovation rate I_N is determined by the exogenous population growth rate as follows

$$I_N = \frac{g_L}{(\log \lambda)(1-\xi)}. \tag{46}$$

Using (23) and (24), the values of assets for northern quality leader and multinational firm in the steady state can be expressed as:

$$v_N(t) = \frac{\pi_N(t)}{\rho + I_N}, \tag{47}$$

$$v_F(t) = \frac{\pi_F(t)}{\rho + I_N + \psi}. \tag{48}$$

Substituting (10) and (47) into (19) yields the following *steady-state innovative R&D condition* such that

$$\beta w_N(t) Q(t)^{1-\zeta} (\rho + I_N) = E(t) \left\{ \phi \left[1 - \frac{w_N(t)}{\lambda(1+\tau_N)} \right] + (1-\phi) \left[\frac{1}{1+\tau_S} - \frac{w_N(t)}{\lambda} \right] \right\}. \tag{49}$$

Similarly, substituting (10), (15), (47) and (48) into (21) yields the following *steady-state adaptive R&D condition* such that

$$\left[\alpha \frac{I_N}{I_N + I_F} + \beta w_N(t) \right] Q(t)^{1-\zeta} (\rho + I_N + \psi) = E(t) \left(1 - \frac{1}{\lambda} \right) \left(\frac{\phi}{1+\tau_N} + 1 - \phi \right). \tag{50}$$

Following Iwaisako and Tanaka (2020), we focus on the case that southern households have no initial assets[8], therefore combining (3) and (29), the budget constraint of a household in the South becomes

$$E_S = 1 + \theta_N E_S \frac{\tau_S}{1+\tau_S}, \tag{51}$$

which implies that the expenditure per capita is the sum of the wage income and the lump-sum transfer of the tariff revenue to the household per capita. Given $E_S = (1-\phi)E(t)/L_S(t)$, equation (51) can be written as

$$1 - \phi = \frac{1+\tau_S}{1+\tau_S(1-\theta_N)} \frac{L_S(t)}{E(t)}. \tag{52}$$

Next, substituting (52) into (44), we obtain ϕ as a function of I_F as follows

$$\frac{\phi}{1-\phi} = (1+\tau_N) \left\{ \left[\frac{I_N}{I_F} + 1 - \frac{\alpha I_N X(1-s)}{s} \right] \left(\frac{1 + \frac{\tau_S}{\frac{I_N}{I_F}+1}}{1+\tau_S} \right) \left(\frac{I_N + \psi}{\frac{I_N}{\lambda} + \psi} \right) - 1 \right\}. \tag{53}$$

Lemma 1. *If the relative southern aggregate expenditure to northern aggregate expenditure $(1-\phi)/\phi$ is sufficiently large, then ϕ is an increasing function of I_F.*

Proof. See Appendix A.1. □

When the relative southern aggregate expenditure to northern aggregate expenditure $(1-\phi)/\phi$ is sufficiently large, an increase in the rate of technology transfer I_F implies that more goods are produced in the South. It decreases the tariff revenue of the southern government and the transfer payment to the southern households, yielding a negative effect on the share of southern aggregate expenditure to world expenditure $1-\phi$. As the share of southern aggregate expenditure and northern aggregate expenditure adds up to unity, the decrease in the share of southern aggregate expenditure to world expenditure corresponds to the increase in the share of northern aggregate expenditure to world expenditure ϕ.[9]

To analyze the steady-state equilibrium, we find out two key equations with respect to I_F and X. Substituting (49) into (39) yields the *northern steady-state condition* such that

$$1 = \beta I_N X \left\{ 1 + \frac{\rho + I_N}{I_N + I_F} \frac{w_N}{\lambda} \frac{\frac{1}{1+\tau_N} + \frac{1-\phi}{\phi}}{\left[1 - \frac{w_N}{\lambda(1+\tau_N)}\right] + \left(\frac{1-\phi}{\phi}\right)\left[\frac{1}{1+\tau_S} - \frac{w_N}{\lambda}\right]} \right\}, \tag{54}$$

which contains two endogenous variables $\{I_F, X\}$ and features a positive slope and a positive X-intercept in the $\{I_F, X\}$ space in Figure 1, where "North" means the northern steady-state

[8]The reason for this setting is to simplify the subsequent calculations to derive the steady-state conditions. Even we assume that southern households have initial assets, we can still derive the same main results.

[9]Lemma 1 is important to ensure the uniqueness of the steady-state equilibrium. If the condition in Lemma 1 is not satisfied, there might exist multiple equilibria or no equilibrium at all.

condition. The intuition behind the positive slope of the northern steady-state condition can be explained as follows. An increase in I_F implies that more products are manufactured in the South and less products are manufactured in the North. This leads to a reallocation of northern labor from production to innovative R&D due to the resources constraint. Therefore, the average quality per northern labor X will increase in the steady-state.

To check it, we denote Γ of (54) as follows

$$\Gamma = \frac{\rho + I_N}{I_N + I_F} \frac{w_N}{\lambda} \frac{\frac{1}{1+\tau_N} + \frac{1}{\phi} - 1}{\left[1 - \frac{w_N}{\lambda(1+\tau_N)}\right] + \left(\frac{1}{\phi} - 1\right) \left[\frac{1}{1+\tau_S} - \frac{w_N}{\lambda}\right]}. \tag{55}$$

We find that Γ is a decreasing function of ϕ. The term Γ decreases when the share of northern aggregate expenditure to world aggregate expenditure ϕ increases. Hence, in (54), to restore to the steady-state, the average quality per northern labor X increases. The following lemma ensures the steady-state value of X.

Lemma 2. Γ *is a decreasing function of* ϕ*.*

Proof. See Appendix A.2 □

Then, substituting (49) and (50) into (44) yields the *southern steady-state condition* such that

$$1 = X \frac{I_F}{I_N + I_F} \left[\frac{\rho + I_N + \psi}{1 - \frac{1}{\lambda}} \left(\frac{\frac{I_N}{\lambda} + \psi}{I_N + \psi} \right) \left(\frac{\alpha I_N}{I_N + I_F} + \beta w_N \right) + \frac{\alpha I_N (1 - s)}{s} \right], \tag{56}$$

which contains two endogenous variables $\{I_F, X\}$ and features a negative slope with no intercept in the $\{I_F, X\}$ space in Figure 1, where "South" means the southern steady-state condition. The intuition behind the negative slope of the southern steady-state condition can be explained as follows. An increase in I_F implies that more products are manufactured in the South, and this leads to a reallocation of southern labor from adaptive R&D to production due to the resources constraint. From (42), an increase in I_F is accomplished by a lower amount of adaptive R&D labor $L_{S,R}(t)$ when the difficulty level $X = Q^{1-\xi}/L_N(t)$ is sufficiently small (i.e. when the technologies become sufficiently easy to be transferred to the South).

Finally, (54) and (56) are the two key conditions that implicitly solve the steady-state equilibrium values of $\{I_F, X\}$.

5 Policy Implications

In this section, we analyze the effects of northern and southern tariffs $\{\tau_N, \tau_S\}$ respectively on the rate of innovation I_N and the rate of technology transfer I_F, in the presence of costly FDI. We first examine the effect of these tariffs on the relative wage w_N. Dividing (50) by (49) yields the following *steady-state relative-wage* condition:

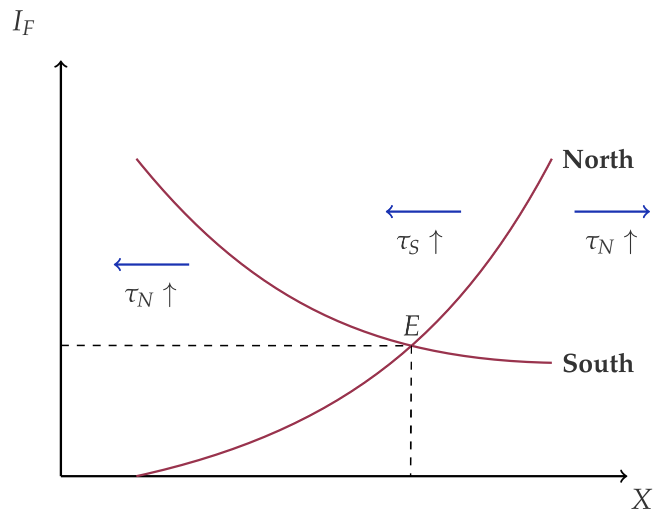

Figure 1: The steady-state equilibrium.

$$\left(\frac{\alpha}{\beta}\frac{\theta_N}{w_N}+1\right)\left[\frac{1+\phi\tau_S}{1+\tau_S}-\frac{w_N}{\lambda}\frac{1+\tau_N(1-\phi)}{1+\tau_N}\right]=\left(1-\frac{1}{\lambda}\right)\left(\frac{\phi}{1+\tau_N}+1-\phi\right)\frac{\rho+I_N}{\rho+I_N+\psi}, \tag{57}$$

which is an implicit function that pins down the steady-state equilibrium value of the relative wage w_N. The following proposition shows the effect of $\{\tau_N, \tau_S\}$ in both countries.

Proposition 1. *Increasing the southern tariff τ_S lowers the relative wage w_N between the northern and southern labor; whereas increasing the northern tariff τ_N raises the relative wage w_N.*

Proof. See Appendix A.3. □

When southern tariff increases, northern quality leaders have to lower the before-tariff price to keep their competitiveness to sell the goods to consumers. This reduces the profits of northern quality leaders and therefore they have less incentive in doing innovative R&D but more incentive in engaging adaptive R&D. This reduces the northern innovation rate but raises the rate of technology transfer. Therefore, the value of assets for multinational firms $v_F(t)$, as shown in (48), becomes relatively higher than the value of assets for northern quality leaders $v_N(t)$, as shown in (47). The zero-profit condition for adaptive R&D in (21) implies that the rise in the return in the adaptive R&D must be associated with the cost in the adaptive R&D labor. The higher cost comes from the higher demand for adaptive R&D labor, which decreases the relative wage between northern and southern labor.

On the other hand, increasing the northern tariff τ_N increases the profits of northern quality leaders through setting a higher markup price. Given θ_N, northern quality leaders can enjoy higher profits, so they have less incentive in engaging adaptive R&D. Thus, the value of assets for northern quality leaders $v_N(t)$, as shown in (47), becomes relatively higher than the value of assets for multinational firms $v_F(t)$, as shown in (48). The zero-profit condition for adaptive R&D in (21) implies that a decline in the return of assets in the adaptive R&D must correspond to a decrease in the cost of adaptive R&D labor, yielding a negative effect on the demand of adaptive R&D labor. As a result, increasing the northern tariff raises the relative wage between the northern and southern labor.

Next, we examine the effects of tariffs on the innovation rate I_N and the technology transfer rate I_F. The following proposition illustrates the impact of an increase in τ_S on I_N and I_F respectively.

Proposition 2. *Increasing the southern tariff τ_S yields (i) a permanent higher rate of technology transfer I_F from the North to the South, and (ii) a temporary lower rate of innovation I_N in the North.*

Proof. See Appendix A.4. □

Graphically, in Figure 1, an increase in τ_S shifts the northern steady-state R&D curve to the left and it has no impact on the southern steady-state R&D curve, leading to a decrease in X and a rise in the rate of technology transfer I_F from the North to the South. Intuitively, as in (10), a rise in τ_S lowers the profits of northern quality leaders as they have to set lower before-tariff prices for consumers, and they have less incentive for doing innovative R&D. Therefore, the rate of innovation I_N decreases and the growth of R&D difficulty X declines. Recall that in Proposition 1, an increase in τ_S lowers the relative wage w_N and therefore it increases $v_F(t)/v_N(t)$. Subsequently, more adaptive R&D are performed by multinational firms, yielding a positive effect on the rate of technology transfer I_F. Iwaisako and Tanaka (2020) show that when FDI is costless, increasing southern tariff raises technology transfer from the North to the South, increases the northern innovation rate and decreases the relative wage between the northern and southern labor. In contrast, we show that unilateral increase in southern tariff reduces the northern innovation rate temporarily when there is costly technology transfer. When transferring the technology from the North to the South, it often requires multinational firms to adapt technologies to local conditions, train workers and build supporting infrastructure. The costs of those adaption can be very high and divert funds away from the innovative activities in the North. As a result, northern quality leaders have less incentive in conducting innovative R&D and the northern innovation rate declines.

The next proposition illustrates the impact of an increase in τ_N on I_N and I_F respectively.

Proposition 3. *Increasing the northern tariff τ_N yields (i) a permanent lower rate of technology transfer I_F from the North to the South, and (ii) a temporary higher (lower) rate of innovation I_N in the North if the North-South labor ratio is sufficiently large (small).*

Proof. See Appendix A.5. □

Graphically, in Figure 1, an increase in τ_N shifts the northern steady-state R&D curve to the right and shifts the southern steady-state R&D curve to the left, leading to an unambiguous decrease in the rate of technology transfer I_F from the North to the South and an ambiguous effect in the rate of innovation I_N in the North. Intuitively, an increase in τ_N increases the lowest possible after-tariff price of a follower's goods imported from the South (i.e., $1 + \tau_N$). Then northern quality leader can set a higher price with quality adjustment by $p_{NN}(t) = \lambda(1 + \tau_N)$ without changing the marginal cost $w_N(t)$. Northern quality leaders can enjoy more profits and have less incentive for conducting adaptive R&D. Therefore, the rate of technology transfer I_F declines when the northern tariff τ_N increases.

Nevertheless, the effect of a rise in the northern tariff τ_N on the rate of innovation I_N in the North is ambiguous. As aforementioned, a higher τ_N increases the profit margin of northern quality leaders, yielding more incentive for them to perform innovative R&D. This leads to a reallocation of labor from production to innovative R&D in the North. In contrast, a higher τ_N leads to a decline in the rate of technology transfer I_F from the North to the South, implying that more products are manufactured in the North and this yields a reallocation of labor from innovative R&D to the production in the North. Next, we analytically examine the ambiguous effect of τ_N on I_N and X. To see this, we use $I_F(t) = I_F$ and (20) to derive

$$I_F = \frac{1}{\alpha} \frac{1}{\theta_N X} \frac{L_{S,R}(t)}{(1-s)L_N(t)}, \tag{58}$$

where $X = Q(t)^{1-\xi}/L_N(t)$ and $L_N(t) = (1-s)L(t)$ are used. In the steady-state, I_F is a function of τ_N and X can be expressed as

$$X = \underbrace{\frac{\frac{I_N}{I_F(\tau_N)} + 1}{\alpha I_N}}_{increasing} \underbrace{\frac{L_{S,R}(t)}{(1-s)L(t)}}_{decreasing}. \tag{59}$$

The (RHS) of (59) comprises two opposing effects on X. The first term on the RHS is increasing in X, capturing the positive effect of τ_N on X as it increases the profits of northern quality leaders. Nevertheless, the second term on the RHS is decreasing in X, capturing the negative effect of τ_N on X as it demands more northern manufacturing labor. The followings explain the two scenarios of the effects of τ_N on X.

On the one hand, X is increasing in τ_N when the North-South labor ratio, $(1-s)/s$, is sufficiently large. This implies that the increase in the northern innovative R&D labor is sufficiently large enough to dominate the negative impact of the reallocation from the innovative R&D labor to manufacturing labor when the decrease in the number of products manufactured by the multinational firms is very minimal. Therefore, the rate of innovation I_N in the North increases temporarily and the average quality per northern worker X increases permanently.

On the other hand, X is decreasing in τ_N when the North-South labor ration, $(1-s)/s$, is sufficiently small, implying that the decrease in the number of products manufactured by the multinational firms is so significant that it demands a large increase in the northern manufacturing labor and surpasses the increase in the innovative R&D labor through higher markup. As a result, the rate of innovation I_N in the North decreases temporarily and the average quality per northern worker X decreases permanently. Iwaisako and Tanaka (2020) show that increasing northern tariff reduces northern innovation and technology transfer from the North to the South, it also raises the relative wage between the northern and southern labor. In contrast, our paper which incorporates costly technology transfer shows that increasing northern tariff yields ambiguous effect on the rate of innovation, depending on the North-South labor ratio.

5.1 Social Welfare

In this section, we examine how the unilateral tariff increases by the North and the South affect welfare respectively. We first decompose the instantaneous utility (1) into utility from quality and utility from quantity as follows

$$\log u_i(t) = \int_0^1 \log \lambda^{J(\omega,t)} d\omega + \int_0^1 \log d_i(\omega,t) d\omega, \tag{60}$$

where $J(\omega,t)$ is the newest generation J of good ω at time t and $d_i(\omega,t)$ is the demand of good ω at time t. We denote by $Q(t)$ and $\log D_i$ as the two terms of RHS of (60) respectively.

Substituting (4) and the prices that the northern consumers pay to northern quality leaders, multinational firms and southern imitating firms into $\log D_N$ yields the utility from quantity as follows

$$\log D_N = \int_0^1 \log d_N(\omega,t) d\omega = \log E_N - (1-\theta_M)\log\lambda - \log(1+\tau_N), \tag{61}$$

and substituting (4) and the prices that the consumers pay to northern quality leaders, multinational firms and southern imitating firms into $\log D_S$ yields the utility from quantity as follows

$$\log D_S = \int_0^1 \log d_S(\omega,t) d\omega = \log E_S - (1-\theta_M)\log\lambda. \tag{62}$$

Rewriting (44), the northern expenditure E_N is expressed as

$$E_N = \frac{1+\tau_N}{L_N(t)} \left[\frac{L_S(t) - \alpha\theta_N I_F Q(t)^{1-\xi}}{\frac{\theta_F}{\lambda} + \theta_M} - E_S(t) L_S(t) \right]. \tag{63}$$

The southern expenditure E_S in (61) and (62) is derived from (51) as follows

$$E_S = \frac{1+\tau_S}{1+\tau_S(1-\theta_N)}. \tag{64}$$

Next, substituting $\dot{Q}(t) = I_N \log \lambda$ into (60) yields the lifetime utility of a household in country i as follows

$$U_i = \frac{1}{\rho - g_L}\left[\log Q(0) + \frac{I_N \log \lambda}{\rho - g_L} + \log D_i\right], \tag{65}$$

where $\log D_i$ is given by (61), (62), (63) and (64). Next, we derive the welfare effect of an increase in tariff τ_i in the North and the South respectively.

We observe the effect on the welfare in the North from an increase in the northern tariff by differentiating the lifetime utility of the northern household with respect to τ_N as follows

$$\frac{\partial U_N}{\partial \tau_N} = \frac{1}{\rho - g_L}\left(\underbrace{\frac{\log\lambda}{\rho - g_L}\frac{\partial I_N}{\partial \tau_N}}_{innovation(+/-)} + \underbrace{\frac{1}{E_N}\frac{\partial E_N}{\partial \tau_N}}_{income(+)} + \underbrace{\log\lambda \frac{\partial \theta_M}{\partial \tau_N}}_{FDI(-)} - \underbrace{\frac{1}{1+\tau_N}}_{price(-)}\right). \tag{66}$$

Equation (66) captures the the overall effect of an increase in the northern tariff on the welfare in the North. First, as in Proposition (3), an increase in northern tariff either increases or decreases innovation, depending on the North-South labor ratio, so the effect on welfare can be positive or negative. Second, as in Proposition (1), increasing the northern tariff raises the relative wage and thus the welfare in the North. Third, as in Proposition (3), increasing the northern tariff impedes the technology transfer from the North to the South, thus less products are imitated by the southern imitators and it decreases the welfare of northern consumers as they can buy less cheaper imitated goods. Last, the increase in northern tariff raises the prices of the products and it thus lowers the welfare of the consumers. Next, we observe the effect on the northern welfare with an increase in the southern tariff. We differentiate the northern household's lifetime utility with respect to τ_S as follows

$$\frac{\partial U_N}{\partial \tau_S} = \frac{1}{\rho - g_L}\left(\underbrace{\frac{\log\lambda}{\rho - g_L}\frac{\partial I_N}{\partial \tau_S}}_{innovation(-)} + \underbrace{\frac{1}{E_N}\frac{\partial E_N}{\partial \tau_S}}_{income(-)} + \underbrace{\log\lambda \frac{\partial \theta_M}{\partial \tau_S}}_{FDI(+)}\right). \tag{67}$$

Equation (67) illustrates the total effect of an increase in the southern tariff on the northern welfare. First, as in Proposition (2), an increase in southern tariff decreases innovation so that consumers can buy less higher-quality products. Second, as in Proposition (1), an increase in southern tariff lowers the relative wage between the northern and southern labor, so thus the northern welfare. Last, as in Proposition (2), an increase in southern tariff promotes technology transfer from the North to the South, more products are imitated and produced with cheaper cost. It increases the welfare of the northern consumers who can benefit from buying cheaper products.

Similarly, we examine the effect on the southern welfare with an increase in the northern tariff. We differentiate the southern household's lifetime utility with respect to τ_N as follows

$$\frac{\partial U_S}{\partial \tau_N} = \frac{1}{\rho - g_L} \left(\underbrace{\frac{\log \lambda}{\rho - g_L} \frac{\partial I_N}{\partial \tau_N}}_{innovation(+/-)} + \underbrace{\frac{1}{E_S} \frac{\partial E_S}{\partial \tau_N}}_{income(-)} + \underbrace{\log \lambda \frac{\partial \theta_M}{\partial \tau_N}}_{FDI(-)} \right). \tag{68}$$

Equation (68) shows the overall effect of an increase in the northern tariff on the southern welfare. First, as in Proposition (3), an increase in the northern tariff either yields positive or negative effect on innovation, depending on the size of the North-South labor ratio. Second, as in Proposition (1), an increase in the northern tariff raises the relative wage between the northern and southern labor and this decreases the welfare of the northern consumers. Last, as in Proposition (3), an increase in the northern tariff lowers the rate of technology transfer. This reduces the welfare of the southern consumers as they are less able to buy cheaper imitated products.

Next, the effect on the welfare in the South from an increase in the southern tariff is derived by differentiating the lifetime utility of the southern household with respect to τ_S as follows

$$\frac{\partial U_S}{\partial \tau_S} = \frac{1}{\rho - g_L} \left(\underbrace{\frac{\log \lambda}{\rho - g_L} \frac{\partial I_N}{\partial \tau_S}}_{innovation(-)} + \underbrace{\frac{1}{E_S} \frac{\partial E_S}{\partial \tau_S}}_{income(+)} + \underbrace{\log \lambda \frac{\partial \theta_M}{\partial \tau_S}}_{FDI(+)} \right). \tag{69}$$

Equation (69) shows the total effect of an increase in the southern tariff on the welfare in the South. First, as shown in Proposition (2), an increase in the southern tariff impedes innovation and thus reduces welfare. Second, as show in Proposition (1), an increase in the southern tariff raises the income of the southern labor and lowers the relative wage, this enhances the welfare in the South. Last, as shown in Proposition (2), the southern tariff increase promotes the FDI and more products are imitated by the southern imitators. As a result, it improves the welfare in the South as consumers can buy cheaper imitated goods.

Due to the complexity to solve the differential equations (66), (67), (68)and (69), we use quantitative analysis to examine the effects of tariffs in the both countries on the steady-state welfare in Section 6.

6 Quantitative Analysis

In this section, we perform the numerical analysis to analyze the effects of northern and southern tariffs on the rate of innovation, technology transfer, relative wage and welfare respectively. We consider the United States as the North and China as the South. When choosing the values of the parameters, we either use the conventional values in previous literature or use the empirical evidence to match the moments of the model. In the end of this section, we perform the robustness checks by altering the values of certain parameters.

6.1 Calibration

The model contains eleven structural parameters $\{\rho, g_L, s, \tau_N, \tau_S, \psi, \phi, \alpha, \beta, \lambda, \xi\}$. For the discount rate ρ, we follow Acemoglu and Akcigit (2012) to set it to 0.05. For the population growth rate g_L, we follow Jones and Williams (2000) to set it to 0.0144. Using the weighted tariff average data from the World Integrated Trade Solution (WITS) from 2015 to 2019, the tariff rate of the US is 2.82%, i.e. $\tau_N = 0.0282$, and the tariff rate of China is 5.72%, i.e. $\tau_S = 0.0572$. We set the relative labor force to the global labor force s be 0.825 which is based on the data from World Development Indicators.[10] According to the data of the final consumption expenditure from World Bank from 2015 to 2019, the share of the aggregate expenditure of the US to the total expenditure of the two countries ϕ is 0.7. For the relative wage between the US and China w_N, we set it to 4.1 according to the average and projection values from the data of the US Bureau of Labor Statistics and National Bureau of Statistics China from 2013-2021. Then we choose the value of the quality step size be $\lambda = 5.5$, so that the condition $\lambda > w_N$ under this two-way product cycle model is satisfied. In the model, it is the relative R&D productivity α/β that determines the values of the equilibrium, therefore we calibrate α/β by matching the relative wage w_N. We set the imitation rate $\psi = 0.03$ in the benchmark model and explore other values in Section 6.4. For the benchmark innovation rate I_N, we follow Zheng *et al.* (2020) to use the conventional value of 0.05 and explore other values of this parameter in the robustness analysis in Section 6.3. Using the population growth rate g_L, the innovation arrival rate I_N and the quality step size λ, we calibrate the R&D externality parameter ξ. Given the calibrated parameter values, we derive the equilibrium values of $\{I_F, X\}$ which are $I_F = 0.020784$ and $X = 3.9307$, respectively. Table 1 summarizes our benchmark parameter values.

Table 1: Parameter values

ρ	g_L	s	τ_N	τ_S	ψ	ϕ	I_N	w_N	α/β	λ	ξ
0.05	0.0144	0.825	0.0282	0.0572	0.03	0.7	0.05	4.1	8.377	5.5	0.831

[10]From Table 2.2 of the Labor Force Structure of the World Development Indicators.

6.2 Benchmark Estimation Result

In this section, we consider three scenarios: (i) an increase in the tariff rate of China τ_S by 1 percentage point, (ii) an increase in the tariff rate of the United States τ_N by 1 percentage point, and (iii) an increase in both tariff rates τ_S and τ_N simultaneously by 1 percentage point. Results are reported in Table 2. The results show that when τ_S increases by 1 percentage point, the rate of technology transfer I_F increases by 1.0883% and the average quality per US worker X decreases by 0.5938%. The increase in τ_S leads to a reduction in the wage gap between the United States and China by 0.3561%. In addition, it leads to a welfare gain of 0.299% in China and a welfare loss of 0.1594% in the United States. From (69), an increase in τ_S increases the labor wage and promotes the FDI in China, the consumers can benefit from buying cheaper imitated goods with higher income. Even the consumers in China can buy less higher-quality innovated products, the overall effect on the welfare is positive as the positive effects on income and FDI dominate the negative impact on innovation. On the contrary, from (67), an increase in τ_S promotes FDI but impedes innovation and decreases labor wage in the US. The negative impacts on the income and innovation dominate the positive impact on FDI, yielding an overall welfare loss in the US.

When the tariff rate of the United States τ_N increases by 1 percentage point, it reduces the rate of technology transfer I_F by 2.5991% and increases the average quality per US worker X by 1.4697% as the US-China labor ratio $(1-s)/s$ is sufficiently large.[11] Moreover, the 1 percentage point increase in τ_N leads to an increase in the wage gap w_N by 0.8827%, a welfare loss of 0.1203% in China and a welfare gain of 0.3353% in the United States. From (68), the overall effect of τ_N on the welfare in China consists of the positive effect on innovation, negative effects on income and technology transfer. Even the consumers in China can benefit from buying more higher-quality innovated products but they suffer from wage loss and being less able to buy cheaper imitated goods. The downside of the wage loss and less available cheaper imitated goods outweigh the positive effect on innovation, yielding a welfare loss in China. In contrast, from (66), the overall effect of τ_N on the welfare in the US consists of the positive effects on innovation and income and the negative effects on technology and price. The welfare gain in the US in general is positive, implying that the positive impacts on innovation and income dominate the negative impacts on technology transfer and price. Our result complements Venables (1987) and Ossa (2014), they show that when the home country increases the tariff rate unilaterally, it enhances the welfare of itself but hurts that of the foreign country.

Furthermore, we perform the numerical analysis when both τ_S and τ_N increase by 1 percentage point simultaneously. The rate of technology transfer decreases by 1.5666% and the average quality per US worker increases by 0.8757%. The increases in both tariff rates widen the US-China wage gap by 0.5263%. The decrease in I_F is partly due to the decrease in adaptive R&D because of the lower demand of southern R&D labor, making the technology transfer from the

[11] The threshold value $\bar{s}$ in (A.15) is negative, which is smaller than the calibrated value of the US-China labor ratio $(1-s)/s = 0.212$.

US to China more difficult. The increase in both τ_S and τ_N leads to a welfare gain of 0.178% in the US and a welfare gain of 0.1782% in China. The welfare gain in the US is mostly due to the increase in wage and the level of innovation X. For China, the increase in the level of innovation crowds out the decrease in the level of technology transfer and labor wage, yielding a welfare gain. In contrast to the above unilateral cases, we find out when τ_S and τ_N increase simultaneously, both countries can benefit from welfare gains. This finding complements Martin and Vergote (2008), they show that when a country imposes optimal tariff, it would be better off and enjoy welfare gain even the other country retaliates. This result can partially explain why the US and China opt to choose non-zero tariff policy.

Table 2: Benchmark simulation

	I_F	X	w_N	U_N	U_S
	0.020784	3.931	4.100	162.522	73.622
$\Delta\tau_S$	0.021016	3.907	4.085	162.263	73.842
$\Delta\tau_N$	0.020244	3.988	4.136	163.067	73.533
$\Delta\tau_S$ & $\Delta\tau_N$	0.020459	3.965	4.122	162.812	73.753

6.3 Robustness Check on the Innovation-Arrival Rate

In this subsection, we alter the value of the innovation arrival rate to perform the robustness checks by considering two alternative values of $I_N \in \{0.08, 0.15\}$ accordingly to Hu *et al.* (2021) and Caballero and Jaffe (1993), respectively. Keeping other parameters unchanged, we redo the numerical analysis by increasing the τ_S and τ_N respectively. Table 3 reports the new simulation results. We see that the larger the innovation arrival rate, the smaller the effects of both southern and northern tariffs on the economic variables except for the relative wage between the United States and China. In the case of $I_N = 0.15$, one percentage point increase in the tariff rate in China increases the rate of technology transfer by 1.0521% and decreases the average quality per US worker by 0.4717%, as compared to 1.0883% and 0.5938% respectively in the benchmark case. Similarly, one percentage point increase in the tariff rate in the United States decreases the rate of technology transfer by 2.5123% and increases the average quality per US worker by 1.1697%, as compared to 2.5991% and 1.4697% respectively in the benchmark case. With one percentage point increase in the tariff rate in China, the United States encounters a smaller welfare loss and China experiences a lesser welfare gain. On the other hand, with one percentage point increase in the tariff rate in the United States, the United States experiences a smaller welfare gain and China experiences a smaller welfare loss with a higher innovation arrival rate. When the tariffs of both countries increase simultaneously by 1 percentage point, we also observe that the higher the innovation rate, the smaller the effects on the economic variables, except for the relative wage. In the case of $I_N = 0.08$, when both tariffs increase by 1 percentage point, the rate of technology transfer decreases by 1.5505%, the average quality per US worker increases by 0.7871% and the relative wage increases by 0.5354% respectively, as compared to -1.5666%, 0.8757% and 0.5263% in the benchmark estimation. The overall effects of the tariffs in both countries are in line with the benchmark case.

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Table 3: Simulation under $I_N \in \{0.08, 0.15\}$

	ΔI_F	ΔX	Δw_N	ΔU_N	ΔU_S
$I_N = 0.08$					
$\Delta\tau_S$	1.0770%	-0.5320%	-0.3622%	-0.1273%	0.1770%
$\Delta\tau_N$	-2.5717%	1.3201%	0.8976%	0.2680%	-0.0584%
$\Delta\tau_S$ &$\Delta\tau_N$	-1.5505%	0.7871%	0.5354%	0.1432%	0.1195%
$I_N = 0.15$					
$\Delta\tau_S$	1.0521%	-0.4717%	-0.3685%	-0.0869%	0.0860%
$\Delta\tau_N$	-2.5123%	1.1697%	0.9127%	0.1851%	-0.0185%
$\Delta\tau_S$ &$\Delta\tau_N$	-1.5146%	0.6975%	0.5444%	0.0998%	0.0681%

6.4 Robustness Check on the Imitation Rate

In this subsection, we perform another robustness check by considering two different values of $\psi \in \{0.05, 0.11\}$ accordingly to Gustafsson and Segerstrom (2011) and Chu *et al.* (2019). Holding other parameters constant, we redo the numerical analysis by increasing the τ_S and τ_N with 1 percentage point respectively. Table 4 reports the simulation results. We find that a higher imitation rate reduces the rate of technology transfer and magnifies the effect on the average quality per US worker. For instance, in the case of $\psi = 0.05$, one percentage point increase in the tariff rate of China increases the rate of technology transfer by 1.051%, compared to 1.0883% in benchmark case, and decreases the average quality per US worker by 0.6331%, compared to -0.5938% in the benchmark case. In addition, we observe that a higher imitation rate increases the welfare gain in China and decreases the welfare loss in the US. In the case of $\psi = 0.05$, when the tariff rate of China increases by 1 percentage point, the welfare gain of China becomes 0.3171%, compared to 0.299% in the benchmark case; the welfare loss of the United States becomes 0.1577% compared to -0.1594% in the benchmark case. When the tariff rate of the US increases by one percentage point, higher imitation rate reduces the welfare gain of the US and increases the welfare loss of China. In the case of $\psi = 0.05$, the welfare gain of the United States becomes 0.3247%, compared to 0.3353% in the benchmark case and the welfare loss of China becomes 0.1464%, compared to -0.1203% in the benchmark case.

When the tariffs of both countries increase by 1 percentage point simultaneously, we see that the higher the imitation rate, the smaller decrease of the technology transfer and the larger increase in the average quality per US worker. In the case of $\psi = 0.11$, the decrease of the rate of technology transfer is 1.4206% as compared to -1.5666% in the benchmark case, while the increase of the average quality per US worker becomes 1.0079% as compared to 0.8757% in the benchmark case. When multinational firms are more threatened by the imitating firms, northern quality leaders have to devote themselves more to develop finer products to avoid imitating firms to capture their market shares, leading to an increase in the average quality per US worker. Moreover, innovating firms have less incentive in shifting the production to the South to become the multinational firms to avoid their products being copies by the southern imitating firms, as a result, the rate of technology transfer declines. The numerical finding is consistent with the finding of Aghion *et al.* (2001) which show that low level of imitation is always growth-enhancing. The magnitude of the increase in the US-China wage gap and the welfare gains of the two countries become smaller when increasing the tariffs in both countries, but the overall pattern is consistent with the benchmark estimation.

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Table 4: Simulation under $\psi \in \{0.05, 0.11\}$

	ΔI_F	ΔX	Δw_N	ΔU_N	ΔU_S
$\psi = 0.05$					
$\Delta\tau_S$	1.0510%	-0.6331%	-0.3500%	-0.1577%	0.3171%
$\Delta\tau_N$	-2.5127%	1.5704%	0.8683%	0.3247%	-0.1464%
$\Delta\tau_S$ &$\Delta\tau_N$	-1.5142%	0.9365%	0.5178%	0.1700%	0.1702%
$\psi = 0.11$					
$\Delta\tau_S$	0.9838%	-0.6815%	-0.3488%	-0.1523%	0.3363%
$\Delta\tau_N$	-2.3585%	1.6897%	0.8671%	0.3065%	-0.1712%
$\Delta\tau_S$ &$\Delta\tau_N$	-1.4206%	1.0079%	0.5168%	0.1567%	0.1640%

7 Conclusion

In this paper, we analyze the effects of tariffs on the relative wage, innovation and technology transfer and welfare, respectively in a North-South Schumpeterian growth model featuring costly FDI and imitation. We find that increasing southern tariff leads to a permanent decrease in the relative wage between northern and southern labor, a permanent higher rate of technology transfer from the North to the South, and a temporary lower rate of innovation in the North. Intuitively, a rise in southern tariff lowers the profit of northern quality leaders as they have to set lower before-tariff prices for southern consumers to keep their competitiveness, therefore they have less incentive for doing innovative R&D but more incentive in shifting the production to the South. Subsequently, more adaptive R&D activities are preformed by multinational firms, yielding a positive effect on the rate of technology transfer and southern wages.

In contrast, increasing northern tariff leads to a permanent increase in the relative wage between northern and southern labor, a permanent decrease in the technology transfer and a higher (lower) northern innovation rate if the North-South labor ratio is sufficiently large (small). Intuitively, an increase in northern tariff increases the lowest possible after-tariff price of a follower's goods imported from the South. Then northern quality leader can set a higher price with quality adjustment without changing the marginal cost. Consequently, Northern quality leaders can enjoy more profits and have less incentive for conducting adaptive R&D. Therefore, the rate of technology transfer declines when the northern tariff increases. It decreases the demand for southern adaptive R&D labor, leading to an increase in the relative wage between northern and southern labor. However, the effect of an increase in northern tariff on the rate of innovation is ambiguous. There are two opposing effects on innovation rate, an increase in northern tariff positively affect innovation rate as it raises the profits of northern quality leaders, however, it negatively affect innovation rate as the decline in technology transfer leads to more demand of northern manufacturing labor but less demand in northern innovative R&D labor. We show that the overall effect on innovation rate depends on the North-South labor ratio.

By using the US-China to calibrate the model, we find that when a country increases tariff unilaterally, it increases the welfare of itself but hurts that of the foreign country. On the other hand, when both countries increase tariff simultaneously, they can benefit from welfare gain. For the US, the welfare gain comes from the increase in wage and the level of innovation. The welfare gain of China mainly comes from the increase in the level of innovation which outweigh the negative impacts on technology transfer and wage.

There are two possible directions to extend this paper for future research. First, we assume exogenous imitation rate in this model for analytical simplicity. However, it would be interesting to endogenize the imitation rate to study the effects of tariff on innovation, technology transfer and welfare. Second, following the canonical North-South Schumpeterian models, we assume that there are no innovative R&D activities in the South. In fact, the R&D expenditure of some developing countries have increased considerably in the recent decade. Specifically, the R&D investment of China increased by 78% from 2016 to 2021 and reached 2.78 trillion yuan in 2021.[12] It is worth incorporating innovative R&D in the South to examine how our analytical results would alter under the settings with these new assumptions.

Appendix A: Proofs of Lemma and Proposition

[12] The data is obtained from the preliminary estimates of China's social Research and Experimental Development from National Bureau of Statistics of China.

A.1 Proof of Lemma 1

From the (54), we denote

$$1=\beta I_N X\left\{1+\underbrace{\frac{1}{I_N+I_F}\underbrace{\frac{w_N(\rho+I_N)}{\lambda}\frac{\frac{1}{1+\tau_N}+\frac{1-\phi}{\phi}}{\left[1-\frac{w_N}{\lambda(1+\tau_N)}\right]+\left(\frac{1-\phi}{\phi}\right)\left[\frac{1}{1+\tau_S}-\frac{w_N}{\lambda}\right]}}_{\epsilon}}_{\Lambda}\right\}. \tag{A.1}$$

We can show that ϵ is an increasing function of $1/\phi$ as follows

$$\frac{\partial\epsilon}{\partial\frac{1}{\phi}}=\frac{w_N(\rho+I_N)}{\lambda}\frac{1-\frac{1}{(1+\tau_N)(1+\tau_S)}}{\left\{\left[1-\frac{w_N}{\lambda(1+\tau_N)}\right]+\left(\frac{1}{\phi}-1\right)\left(\frac{1}{1+\tau_S}-\frac{w_N}{\lambda}\right)\right\}^2}>0. \tag{A.2}$$

Next, substitute (33), (34) and (35) into (53) and rearrange it as

$$\frac{1}{\phi}=\frac{1}{(1+\tau_N)\left\{\left[\frac{I_N}{I_F}+1-\frac{\alpha I_N X(1-s)}{s}\right]\frac{1+\frac{\tau_S}{\frac{I_N}{I_F}+1}}{1+\tau_S}\frac{I_N+\psi}{\frac{I_N}{\lambda}+\psi}-1\right\}}+1. \tag{A.3}$$

Then, we can differentiate $1/\phi$ with respect with I_F to show that $1/\phi$ is an increasing function of I_F as follows

$$\frac{\partial\frac{1}{\phi}}{\partial I_F}=\frac{\frac{1+\tau_N}{1+\tau_S}\frac{I_N+\psi}{\frac{I_N}{\lambda}+\psi}\frac{I_N}{I_F{}^2}\left[1+\frac{\tau_S\alpha I_N X(1-s)}{s\left(\frac{I_N}{I_F}+1\right)^2}\right]}{\left\{\left[\frac{I_N}{I_F}+1-\frac{\alpha I_N X(1-s)}{s}\right]\left(1+\frac{\tau_S}{\frac{I_N}{I_F}+1}\right)\frac{1+\tau_N}{1+\tau_S}\frac{I_N+\psi}{\frac{I_N}{\lambda}+\psi}-(1+\tau_N)\right\}^2}>0. \tag{A.4}$$

Since $\Lambda=\epsilon/(I_N+I_F)$, to ensure that Λ is a decreasing function of I_F, the following condition has to be satisfied

$$\begin{aligned}\frac{\partial\Lambda}{\partial I_F} &= \frac{\frac{\partial\epsilon}{\partial I_F}(I_N+I_F)-\epsilon}{(I_N+I_F)^2}<0\\ &\Rightarrow \frac{\partial\epsilon}{\partial\frac{1}{\phi}}\frac{\partial\frac{1}{\phi}}{\partial I_F}(I_N+I_F)-\epsilon<0\\ &\Rightarrow \epsilon>\frac{\partial\epsilon}{\partial\frac{1}{\phi}}\frac{\partial\frac{1}{\phi}}{\partial I_F}(I_N+I_F). \end{aligned} \tag{A.5}$$

Next, substitute (A.2) and (A.4) into (A.5) yields

$$\frac{1-\phi}{\phi} > \frac{\left[1-\frac{1}{(1+\tau_N)(1+\tau_S)}\right](I_N+I_F)}{1-\frac{w_N}{\lambda(1+\tau_N)}+\left(\frac{1-\phi}{\phi}\right)\left(\frac{1}{1+\tau_S}-\frac{w_N}{\lambda}\right)}\frac{\partial\frac{1}{\phi}}{\partial I_F}-\frac{1}{1+\tau_N}. \tag{A.6}$$

Denote the RHS of (A.6) as $\bar{\phi}$, we conclude that the relative aggregate expenditure to the northern aggregate expenditure has to be sufficiently larger than $\bar{\phi}$ in order to obtain the unique equilibrium.

A.2 Proof of Lemma 2

Denote $\mu = (1/\phi) - 1$, then differentiate (55) it with respect to μ yields

$$\frac{\partial\Gamma}{\partial\mu} = \frac{w_N(\rho+I_N)}{\lambda(I_N+I_F)}\left\{\frac{1-\frac{1}{(1+\tau_N)(1+\tau_S)}}{\left[1-\frac{w_N}{\lambda(1+\tau_N)}+\mu(\frac{1}{1+\tau_S}-\frac{w_N}{\lambda})\right]^2}\right\} > 0, \tag{A.7}$$

because $1-[1/(1+\tau_N)(1+\tau_S)] > 0$. Since $\partial\mu/\partial\phi = -1/\phi^2 < 0$, the effect of of ϕ on Γ is given by

$$\frac{\partial\Gamma}{\partial\phi} = \underbrace{\frac{\partial\Gamma}{\partial\mu}}_{>0} \times \underbrace{\frac{\partial\mu}{\partial\phi}}_{<0} < 0. \tag{A.8}$$

Therefore ϕ is a decreasing function of Γ. An increase in ϕ leads to a decrease in Γ.

A.3 Proof of Proposition 1

We first examine the effect of τ_S on w_N. Before doing so, we re-arrange (57) as follows

$$\begin{aligned} F(w_N,\tau_S,\tau_N) = &\left(\frac{\alpha}{\beta}\frac{\theta_N}{w_N}+1\right)\left[\frac{1+\phi\tau_S}{1+\tau_S}-\frac{w_N}{\lambda}\frac{1+\tau_N(1-\phi)}{1+\tau_N}\right] \\ &-\left(1-\frac{1}{\lambda}\right)\left(\frac{\phi}{1+\tau_N}+1-\phi\right)\frac{\rho+I_N}{\rho+I_N+\psi} = 0. \end{aligned} \tag{A.9}$$

Then, using implicit function to solve (A.9) as follows

$$\frac{\partial w_N}{\partial\tau_S} = -\frac{F_{\tau_S}}{F_{w_N}} = \frac{\left(\frac{\alpha}{\beta}\frac{\theta_N}{w_N}+1\right)\left[\frac{\phi-1}{(1+\tau_N)^2}\right]}{\frac{\alpha}{\beta}\frac{\theta_N}{w_N{}^2}\frac{1+\phi\tau_S}{1+\tau_S}+\frac{1}{\lambda}\left[\frac{1+\tau_N(1-\phi)}{1+\tau_N}\right]} < 0, \tag{A.10}$$

because $\phi - 1 < 0$. Given that (A.10) is a decreasing function of w_N, an increase in τ_S leads to a lower w_N. Next, we examine the effect of τ_N on w_N by using implicit function to solve (A.9) as follows

$$\frac{\partial w_N}{\partial \tau_N} = -\frac{F_{\tau_N}}{F_{w_N}} = \frac{\frac{\phi}{(1+\tau_N)^2}\left[\frac{w_N}{\lambda} + \frac{\alpha}{\beta}\frac{\theta_N}{\lambda} + (1-\frac{1}{\lambda})\frac{\rho+I_N}{\rho+I_N+\psi}\right]}{\frac{\alpha}{\beta}\frac{\theta_N}{w_N{}^2}\frac{1+\phi\tau_S}{1+\tau_S} + \frac{1}{\lambda}\left[\frac{1+\tau_N(1-\phi)}{1+\tau_N}\right]} > 0, \tag{A.11}$$

because $1 - 1/\lambda > 0$. Given that (A.11) is an increasing function of w_N, an increase of τ_N leads to a higher w_N.

A.4 Proof of Proposition 2

We can show graphically in Figure 1 that a rise in τ_S shifts the northern steady-state R&D curve to the left and it has no effect on the southern steady-state R&D curve. Therefore, a rise in τ_S leads to a decrease in X and an increase in I_F. As in (45), a permanent decrease in X corresponds to a temporary decrease in the innovation rate I_N above its steady-state level in (46). This completes the proof of proposition 2.

A.5 Proof of Proposition 3

Graphically, in Figure 1, an increase in northern tariff τ_N shifts the North curve to the right and the South curve to the left, resulting in a decrease in the rate of technology transfer I_F from the North to the South. This completes the proof of (i) of proposition 3.

For (ii), we rewrite I_F from (54) to

$$I_F = \frac{\beta I_N X}{1-\beta I_N X}\frac{w_N(\rho+I_N)}{\lambda}\frac{\frac{1}{1+\tau_N} + \frac{1-\phi}{\phi}}{1 - \frac{w_N}{\lambda(1+\tau_N)} + \left(\frac{1-\phi}{\phi}\right)\left(\frac{1}{1+\tau_S} - \frac{w_N}{\lambda}\right)} - I_N, \tag{A.12}$$

and substituting it into (56) and yields

$$\begin{aligned} F(X,\tau_N) =& X\left\{1 - \frac{\lambda(1-\beta I_N X)\left[1 - \frac{w_N}{\lambda(1+\tau_N)} + \left(\frac{1-\phi}{\phi}\right)\left(\frac{1}{1+\tau_S} - \frac{w_N}{\lambda}\right)\right]}{\beta X w_N(\rho+I_N)\left(\frac{1}{1+\tau_N} + \frac{1-\phi}{\phi}\right)}\right\}\times \\ &\left\{\frac{\alpha\eta\lambda(1-\beta I_N X)\left[1 - \frac{w_N}{\lambda(1+\tau_N)} + \left(\frac{1-\phi}{\phi}\right)\left(\frac{1}{1+\tau_S} - \frac{w_N}{\lambda}\right)\right]}{\beta X w_N(\rho+I_N)\left(\frac{1}{1+\tau_N} + \frac{1-\phi}{\phi}\right)} + \beta w_N\eta + \frac{\alpha I_N(1-s)}{s}\right\} - 1 = 0, \end{aligned} \tag{A.13}$$

where we denote

$$\eta = \left(\frac{\rho + I_N + \psi}{1 - \frac{1}{\lambda}}\right)\left(\frac{\frac{I_N}{\lambda} + \psi}{I_N + \psi}\right). \tag{A.14}$$

Next, applying implicit function theorem and differentiating (A.13) with respect to τ_N yields

$$\begin{aligned}\frac{\partial X}{\partial \tau_N} &= -\frac{F_{\tau_N}}{F_X} \gtrless 0 \\ \Rightarrow \frac{1-s}{s} &\gtrless \frac{\beta B(1+\tau_N)\left[\left(\frac{\lambda A}{B w_N}-1\right)\left(1+\frac{2\lambda\eta AC}{X\beta B w_N}\right)\frac{\alpha C}{\beta B(1+\tau_N)^2}-\left(w_N-\frac{\lambda A}{B}\right)\frac{C}{\eta B(1+\tau_N)^2}\right]}{\alpha I_N\left[\frac{1}{\lambda}+\frac{\lambda A}{w_N B(1+\tau_N)}\right]}\end{aligned} \quad (A.15)$$

where we denote

$$\begin{aligned} A &= 1-\frac{w_N}{\lambda(1+\tau_N)}+\frac{1-\phi}{\phi}\left(\frac{1}{1+\tau_S}-\frac{w_N}{\lambda}\right), \\ B &= \frac{1}{1+\tau_N}+\frac{1-\phi}{\phi}, \\ C &= \frac{1-\beta I_N X}{\rho+I_N}. \end{aligned}$$

We denote the RHS of (A.15) as $\bar{s}$. Therefore, when the North-South labor ratio is sufficiently large, $(1-s)/s > \bar{s}$, an increase in northern tariff τ_N increases the average quality per northern worker X permanently and it also raises the rate of innovation in the North I_N temporarily. However, when the North-South labor ratio is sufficiently small, $(1-s)/s < \bar{s}$, an increase in northern tariffτ_N decreases the average quality per northern worker X permanently and it also reduces the rate of innovation in the North I_N temporarily. This completes the proof of (ii) of proposition 3.

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