Who Starts the Trade War?
A Theory of Export Controls and Quid Pro Quo[*]

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Abstract

China has been accused of its *quid pro quo* policy which requires multinational firms to transfer technologies in return for market access. What is less well-known is that developed countries have imposed export controls on a large variety of high-tech products to China. We develop a simple two-country model to understand the motives and consequences of these non-traditional trade and FDI policies. Under certain regularity conditions, we show that the coexistence of export controls and quid pro quo is the unique Nash equilibrium in this game. Comparing to the world without policy interventions, both countries are worse off in the non-cooperative equilibrium. Therefore, both countries can benefit from international cooperation on knowledge sharing.

Keywords: *Trade Policy*; *Export Controls*; *Quid Pro Quo*; *Knowledge Competition*; *Knowledge Sharing.*

JEL classification: *F12*; *F13*; *F23*; *O24*.

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If there's a trade war between the U.S. and China, don't blame Donald Trump: China started it long before he became president.
–The Wall Street Journal, March 23, 2018.

1 Introduction

Nowadays trade policy is far beyond tariff and, in particular, intertwined with FDI policy. In the recent US-China trade conflicts, the U.S. accused that China had imposed high import tariffs to induce inward FDI and implemented *quid pro quo* policy which requires multinationals to transfer technologies in return for market access.[1] What is less well-known is that the U.S., together with other developed countries, have imposed export controls on a large variety of high-tech products to China. For example, until 2010, China was prohibited to import lithography systems for producing <90nm semiconductors.[2] Yet, trade theories have paid little attention to the motives and consequences of these nontraditional trade policies. This paper aims to fill the gap between theory and policy practice.

We develop a two-country ("North" and "South") Krugman model with trade and multinational production (MP). A continuum of manufacturing goods are produced in a Dixit-Stiglitz world. The key assumption is that each manufacturing variety can be produced by *two* alternative technologies: technology 1 is to combine labor with a tradable strategic good that can only be produced in the North, whereas technology 2, exclusive to North firms, is to produce by labor only. Without any policy intervention, the South has two ways to access manufacturing technologies: (1) buying strategic goods from the North or (2) allowing the North firms to produce in the South.

How would countries intervene trade and FDI in this environment? We first show that the North gains from export controls on strategic goods to the South. Doing this, the North monopolizes the manufacturing production and benefits from home market effects. Facing this export control, the South has incentives to implement quid pro quo policy in order to get an access to manufacturing technologies.[3] Under certain regularity conditions, we show

[1] In the Wall Street Journal on March 23, 2018, "Even free traders and internationalists agree China's predatory trade practices–which include forcing U.S. business to transfer valubale technology to Chinese firms and restricting acess to Chinese markets–are undermining both its partners and the trading system."

[2] After 2010, China was prohibited to import lithography systems for producing <45nm semiconductors. Other economies such as Korea and Taiwan have not been subject to similar restrictions. See the control list of the *Wassenaar Arrangement* on https://www.wassenaar.org/

[3] We do not consider the voluntary technology transfer or technology spillover from multinationals to local firms. One reason is to simplify the model and focus on the main point. Another reason is that

that the coexistence of export controls and quid pro quo is the unique Nash equilibrium in this game. Interestingly, comparing to the world without policy intervention, both countries are worse off in equilibrium.

Why do both countries lose in this non-traditional trade war featured with export control and quid pro quo? The key is the international competition for knowledge, a salient feature of international competition in recent years. By restricting the exports of strategic goods, the North aims to monopolize the knowledge embedded in these goods. However, in the era of global production, the South can bypass this technology embargo by quid pro quo policy. When the South market is sufficiently large, *the North multinational firms* will transfer their technologies in return for market access, deviating from the best interest of *the North country*. To monopolize or to get an access to knowledge, both countries distort international trade and FDI. The efficiency losses led by these distortions thus call for a new agenda for international cooperation on knowledge sharing.

This paper is the first theoretical characterization for the linkages between export controls and quid pro quo. It relates to an extensive literature on the consequences of globalization. Samuelson (2004) points out that the North can be hurt by the South's dramatic productivity improvement in industries where the North has comparative advantage initially. In this context, it is of the North's best interest to restrict the exports of strategic goods and suppress the South's improvement on manufacturing technologies. This paper departs from his work by emphasizing that the North's attempt to monopolize technologies may not be achieved in the era of global production. The South can distort international trade and induce technology transfer by quid pro quo. Both countries will be better off if they go back to the world without policy interventions.

This paper contributes to the theoretical discussions about trade policy including Johnson (1953), Krugman (1980), Venables (1987), Grossman and Helpman (1994), Bagwell and Staiger (1999), and Ossa (2011). In this paper, like Ossa (2011), countries distort international trade in order to gain from production relocation. Moreover, countries are trapped in a prisoner's dilemma if they implement their trade policies noncooperatively. This paper departs from Ossa (2011) by focusing on the nontraditional trade and FDI policies such as export controls of strategic goods and quid pro quo.

This paper also relates to the studies on China's quid pro quo policy. Holmes et al. (2015) suggest that China benefits significantly from quid pro quo at the expense of developed countries. This paper points out that quid pro quid is the China's best response to developed

the empirical studies have found insignificant or small technology spillovers from foreign firms in China to Chinese local firms. See details in the literature review.

countries' export controls on strategic goods. With international cooperation on knowledge sharing, China would abandon quid pro quo in return of access to strategic goods.

Finally, this paper is related to the empirical studies on technology spillovers from multinationals to local firms in the host country. If FDI technology spillover is sufficiently large, then quid pro quo policy makes little sense. However, using Chinese firm data and exogenous policy shocks as instruments, Lu, et al. (2017) find that FDI has a negative and significant effect on the productivity of domestic firms in the same industry. Liu, et al. (2017) further point out that it is wholly-foreign-owned firms in China that contribute to this negative spillover effect. Jiang et al. (2018) find that the joint venture leads to technology spillovers to Chinese partner firms and also other Chinese firms in the same industry. These findings suggest that quid pro quo is crucial for Chinese firms to get an access to advanced technologies.

The paper is structured as follows. Section 2 introduces model specification. Section 3 discusses welfare implications of different policy combinations. Section 4 characterizes Nash equilibrium in this game. Section 5 extends the model to discuss the North's retaliation to quid pro quo and the possibility of international cooperation in a repeated game. Section 6 concludes.

2 Model

2.1 Preference

There are two countries in the world: North (N) and South (S). Each country is endowed with L workers. There are two final goods: manufacturing good and raw good. We assume that raw good is homogeneous, produced one-to-one form labor under perfect competition, and freely traded. So we take its price as the numeraire.

The representative consumer in country $i \in \{N, S\}$ has a Cobb-Douglas preference:

$$U_i = \left(C_i^M\right)^\alpha \left(C_i^R\right)^{1-\alpha}, \quad \alpha \in (0,1), \tag{1}$$

where (C_i^M, C_i^R) are, respectively, country i's consumption of manufacturing good and raw good.

2.2 Technology

Manufacturing good consists of a continuum of varieties that are aggregated by a CES function with the elasticity of substitution $\sigma > 1$. Each variety is produced by a firm under monopolistic competition. After paying a fixed entry cost f^e in terms of labor in their own country, the firm can (potentially) produce manufacturing goods using two alternative technologies described below:

Technology 1: The manufacturing goods can be produced by combining labor and a high-tech strategic good:

$$Q_i^H(\omega) = T \min\{L_i(\omega), H_i(\omega)\}, \tag{2}$$

where the productivity $T > 2$, $L_i(\omega)$ is the labor used in producing variety ω of manufacturing good, and $H_i(\omega)$ is the inputs of strategic goods. This technology is available to all firms *once the strategic good is available.* The strategic good can only be produced one-to-one from labor in the North under perfect competition.

We consider the Leontief production to highlight the importance of strategic goods in manufacturing production and to simplify the equilibrium characterization. As discussed in Appendix A.2, our main results do not rely on this specific production function. The key assumption for technology 1 is that the strategic good can only be produced in the North.

Technology 2: The manufacturing good can be produced one-by-one from labor. This technology is only available to the North firms.

2.3 Trade and MP Costs

Firms can serve the foreign market after incurring an iceberg trade cost $\tau > 1$. Moreover, firms in the North can offshore their production to the South after paying a fixed MP cost f^M in terms of labor in the North. MP also incurs an iceberg MP cost, $\gamma > 1$.[4] In contrast, strategic goods can be traded freely across countries, whereas its production cannot be offshored. Semiconductor chip is an example of high-tech strategic goods: (i) it is difficult to be substituted; (ii) its transportation cost is low relative to its value; and (iii) it can only be produced in a very limited set of countries.

For simplicity, we assume that $1-\alpha$ is sufficiently large so that each country will produce

[4]This iceberg MP cost is meant to capture the various costs of communication and technology transfer incurred by multinationals for operating in markets far away from their home countries. It is consistent with the fact that multinationals' sales tend to be smaller in the host countries farther way from their headquarters (see Antras and Yeaple (2014) for the empirical regularities). This cost has been incorporated in recent MP models such as Ramondo and Rodriguez-Clare (2013), Tintelnot (2016), and Arkolakis et al. (2018).

raw good. Therefore, the wage is pinned down by the numeraire, $w = 1$.

2.4 Equilibrium without Intervention

We characterize the benchmark equilibrium in absence of policy interventions on trade and FDI. We assume that τ is sufficiently low or f^M is sufficiently high so no FDI occurs without policy interventions. Since strategic good is freely traded and $T > 2$, all firms will choose technology 1 to produce manufacturing goods. The unit cost of producing manufacturing goods in each country is thus $\frac{2}{T}$.

Let M_i be the mass of firms producing manufacturing goods in country i. Free entry condition implies that for any $i \in \{N, S\}$

$$M_i = \frac{\alpha L}{\sigma f^e}. \tag{3}$$

Let P_i be the price index for final goods in country i. Country i's welfare can be measured by its real wage, $W_i := \frac{1}{P_i}$. For any $i \in \{N, S\}$, the welfare without policy interventions can be expressed as

$$\begin{aligned} W_i^{Free} &= \left[P_i^{free}\right]^{-1} \\ &= \left[M_i \left(\frac{2}{T}\right)^{1-\sigma} + M_{-i} \left(\frac{2\tau}{T}\right)^{1-\sigma}\right]^{-\frac{\alpha}{1-\sigma}} \\ &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} \left(\frac{T}{2}\right)^{\alpha} \left(1 + \tau^{1-\sigma}\right)^{\frac{\alpha}{\sigma-1}}. \end{aligned} \tag{4}$$

Notably, we assume that strategic good is freely traded. Under this assumption, Equation (4) implies that without policy interventions welfare is equalized across countries. Having trade costs for strategic goods will inhibit technology transfers from North to South and thereby decrease the South's welfare. However, our policy discussions below do not depend on this simplifying assumption.

2.5 Trade and FDI Policies

Motivated by the policy debates in recent trade conflicts, we focus on two types of policies: (1) the North can restrict the exports of strategic goods; (2) the South can require the North firms to transfer technologies to the South firms in return for producing and making sales in the South.

Notice that we have set the parameters so that no FDI occurs initially. Therefore, import restriction is a prerequisite to quid pro quo. Moreover, as discussed in the introduction, we do not consider voluntary technology transfer or technology spillover from multinationals to local firms. We assume that two countries act simultaneously.

Table 1: Payoff Matrix for the North and South

		North: Export Controls (EC)	
		Yes	No
South: Import restriction	Yes	(W_S^{QPQ}, W_N^{QPQ})	(W_S^{FDI}, W_N^{FDI})
& Quid Pro Quo (QPQ)	No	(W_S^{EC}, W_N^{EC})	(W_S^{Free}, W_N^{Free})

The game structure is presented by the payoff matrix in Table 1. Notably, when the North does *Not* restrict export of strategic goods, quid pro quo will not be effective since the South firms have an access to technology 1, which is more productive than technology 2. Therefore, (W_S^{FDI}, W_N^{FDI}) corresponds to the case where the North serves the South by FDI and the South produces manufacturing goods using technology 1.

3 Welfare Implications of Policy Combinations

3.1 Export Controls on Strategic Goods

In this subsection, we characterize the welfare effects of the North's export controls on strategic goods. In Table 1, we let the North's strategy space be binary: it either puts no restrictions on the exports of strategic goods or completely bans it. The following result shows that if the South does not impose quid pro quo, it is optimal for the North to impose a prohibitive export tariff on strategic goods. So it is reasonable to simplify the North's strategy space into a binary set.[5]

Proposition 1 (Optimal Export Tariff on Strategic Goods) *Suppose the North imposes an iceberg exporting cost for strategic goods, $t \geq 1$. Suppose that the South does not impose import restriction or quid pro quo. Then in equilibrium $M_S > 0$ if and only if $t < 2\left(\frac{\tau^{\sigma-1}+\tau^{1-\sigma}}{2}\right)^{\frac{1}{\sigma-1}} - 1$. Moreover, the North's welfare is strictly increasing with t when $t \leq 2\left(\frac{\tau^{\sigma-1}+\tau^{1-\sigma}}{2}\right)^{\frac{1}{\sigma-1}} - 1$ and constant for all $t > 2\left(\frac{\tau^{\sigma-1}+\tau^{1-\sigma}}{2}\right)^{\frac{1}{\sigma-1}} - 1$.*

[5]We will show later that even when the South imposes quid pro quo, under certain regularity conditions, it is still optimal for the North to ban the exports of strategic goods.

When the North bans the export of strategic goods and the South does not impose quid pro quo, the welfare can be expressed as

$$\begin{aligned} W_N^{EC} &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} \left(\frac{T}{2}\right)^{\alpha} 2^{\frac{\alpha}{\sigma-1}}, \\ W_S^{EC} &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} \left(\frac{T}{2}\right)^{\alpha} \left(2\tau^{1-\sigma}\right)^{\frac{\alpha}{\sigma-1}}. \end{aligned} \tag{5}$$

Combining Equation (4) and (5), we show that if the South does not impose quid pro quo, the North gains from export controls on strategic goods at the expense of the South:

Proposition 2 (The North's Gains from Export Controls)

$$W_S^{EC} < W_S^{Free} = W_N^{Free} < W_N^{EC}. \tag{6}$$

Intuitively, if the South does not impose quid pro quo, it is of the North's best interest to ban its exports of strategic goods and monopolize manufacturing technologies. Doing this the North induces entrants in the manufacturing sector and gains from this home market effect, at the expense of the South.

3.2 Quid Pro Quo

In this subsection, we examine the effects of quid pro quo when the North bans the exports of strategic goods. As mentioned above, the South requires the North firms to transfer technologies in return for producing and making sales in the South. If the North firms accept the offer, technology 2 will be transfered since the strategy good is not available to the South. We first propose the following regularity conditions:

Assumption 3 (Regularity Conditions) *We assume that*

1. $2 < \frac{\tau^{\sigma-1} - \gamma^{1-\sigma}\left(\frac{T}{2}\right)^{1-\sigma}}{\left(\frac{T}{2}\right)^{\sigma-1} - \tau^{1-\sigma}} < \tau^{\sigma-1} + 1.$
2. $\tau < \gamma < \infty.$
3. $2 - \tau^{\sigma-1}\left(\frac{T}{2}\right)^{\sigma-1} < \gamma^{1-\sigma} < \frac{1}{2-\tau^{1-\sigma}\left(\frac{T}{2}\right)^{1-\sigma}}.$

Then we have the following results:

Proposition 4 (Quid Pro Quo) *Suppose that the North bans its exports of strategic goods. Suppose that the regularity conditions in Assumption 3 hold. Then*

1. *The North firms will accept the South's offer of quid pro quo.*

2. $W_N^{FDI} < W_N^{QPQ} < W_N^{Free}$ *and* $W_S^{EC} < W_S^{QPQ} < W_S^{Free}$

.

It is worth providing some intuition for the regularity conditions in Assumption 3. First, if the North firms accept the South's offer of quid pro quo, they gain from getting an access to the South market but lose from the South's import competition. Notably, Condition 1 in Assumption 3 implies that $\left(\frac{T}{2}\right)^{\sigma-1} > \tau^{1-\sigma}$, which is the sufficient and necessary condition for the North firms to accept the South's offer of quid pro quo. Intuitively, larger τ indicates that the North faces less import competition from the South.

Second, Condition 2 in Assumption 3 indicates that MP is more costly than trade. So it is less profitable for the North firms to serve the South through MP than trade, which leads to $W_N^{QPQ} < W_N^{Free}$.

Third, if the iceberg MP cost γ is much larger than the iceberg trade cost τ, the South will prefer importing manufacturing goods to quid pro quo. To avoid this case, Condition 1 in Assumption 3 provides an upper bound for γ in terms of τ and T.

Finally, Condition 3 in Assumption 3 ensures that both countries have positive masses of manufacturing firms under quid pro quo.

In sum, when (i) τ is large so that the North multinationals do not worry about the South's import competition, and (ii) γ is bounded above by a combination of τ and T so that the South prefers quid pro quo to importing manufacturing goods, it is optimal for the South to impose quid pro quo and the North firms will accept the offer. Moreover, when MP is more costly than trade, i.e. $\gamma > \tau$, quid pro quo makes the North worse off than free trade.

4 Equilibrium

Armed by welfare implications of different policy combinations, we now characterize the Nash equilibrium for the game described by Table 1. Then we get our main result of this paper:

Proposition 5 (Nash Equilibrium) *Suppose that Assumption 3 holds. Then the unique Nash equilibrium for the game in Table 1 is that the North bans its exports of strategic goods and the South imposes quid pro quo. The equilibrium welfare is* (W_S^{QPQ}, W_N^{QPQ}) *such that* $W_S^{QPQ} < W_S^{Free}$ *and* $W_N^{QPQ} < W_N^{Free}$.

Proof. From Proposition 2 and Proposition 4, banning the exports of strategic goods is the dominant strategy for the North. Since $W_S^{EC} < W_S^{QPQ}$, the unique Nash equilibrium for the game in Table 1 is that the North bans its exports of strategic goods and the South imposes quid pro quo. ■

What lies in the center of this game is the international competition for knowledge. Under Assumption 3, banning the exports of strategic goods is the North's dominant strategy. Intuitively, since technology 1 is much more productive than technology 2, it is of the North's best interest to monopolize this technology. In response of the North's export controls, it is of the South's best interest to impose quid pro quo since this is its only way to get an access to manufacturing technology. Comparing to the world without intervention, the South is worse off because technology 2 is less productive than technology 1, whereas the North is worse off because it serves the South by FDI, which is more costly than trade.

5 Extensions

In this section, we extend our model to discuss further policy interactions between the North and South and the possibility of international cooperation in a repeated game. The purpose is to explore the theoretical implications of our model to recent policy debates in the trade conflicts. We first discuss the implications of the North's restriction on manufacturing imports. Then we characterize the effects of the North's restriction on outward FDI. And finally we investigate the possibility of international cooperation.

5.1 The North's Restriction on Manufacturing Imports

In this subsection, we extend our model to analyze two policy tools by which the North can retaliate the South's quid pro quo: (1) banning manufacturing imports from the South, and (2) banning manufacturing FDI to the South.

Suppose that the North bans manufacturing imports from the South. Would the South abandon quid pro quo? Can the North gain from this retaliation? In this section, we assume that the North has banned its exports of strategic goods.

Notice that if the South abandon quid pro quo, the North will monopolize manufacturing production and the South's welfare is W_S^{EC} under $\gamma > \tau$. Now suppose that the South does not abandon quid pro quo. Denote the welfare in this case as (W_S^{RT}, W_N^{RT}).

Proposition 6 (Welfare Consequences of Retaliation) *Suppose that* $\tau^{\sigma-1} > 2\left(\frac{T}{2}\right)^{\sigma-1}$. *Then we have* $W_S^{RT} > W_S^{EC}$, *i.e. the North's manufacturing import control cannot make the*

South abandon its quid pro quo. Moreover, we have $W_N^{RT} > W_N^{QPQ}$ but $W_S^{RT} < W_S^{QPQ}$, i.e. the North gains from this retaliation at the South's expense.

Intuitively, when $\tau^{\sigma-1} > 2\left(\frac{T}{2}\right)^{\sigma-1}$, the North's technology advantage in manufacturing production is not sufficiently strong. So the North's manufacturing import control cannot make the South abandon its import restriction and quid pro quo.

When the North bans manufacturing imports, if the South does not abandon its import restriction and quid pro quo, it must rely on its domestic market to support the manufacturing production. Therefore, relative country size is critical to the South's decision. To understand this market size effect, we extend our model to allow for asymmetric country size. We have the following corollary for Proposition 6.

Corollary 7 (Asymmetric Country Size) *Denote the North's population as $L = L_N$ and the relative country size as $r = L_S/L_N$. Suppose that $\tau^{\sigma-1} > \left(\frac{1+r}{r}\right)\left(\frac{T}{2}\right)^{\sigma-1}$. Then we have $W_S^{RT} > W_S^{EC}$, i.e. the North's manufacturing import control cannot make the South abandon its quid pro quo.*

Corollary 7 shows that if the South has larger population, it is less likely to abandon quid pro quo under the North's import restriction.

5.2 The North's Restriction on Outward FDI

We proceed by considering the case in which the North retaliates by banning its manufacturing FDI in the South. Given this FDI restriction, the South will abandon its restrictions on manufacturing imports; otherwise it has no access to manufacturing goods. The welfare is then (W_S^{EC}, W_N^{EC}). In this sense, banning FDI and exports of strategic goods would be the most effective strategy for the North to force the South to abandon quid pro quo. However, doing so may not be the equilibrium strategy in a static game.

We consider the following game: the North chooses between banning manufacturing FDI or not, whereas the South chooses between imposing import restriction and quid pro quo or not. For simplicity, we assume that in this game the North always bans the exports of strategic goods.

Notice that $W_N^{FC} = \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}}\left(\frac{T}{2}\right)^{\alpha}$. We can show that if $T > 2$, $W_N^{FC} < W_N^{QPQ}$. Therefore, there are two pure strategy Nash equilibria in the game: (QPQ, No FC) and (No QPQ, FC). This game is the game of chicken: both players try to avoid the conflicts in which the North bans its outward FDI and the South imposes quid pro quo. If the North believes

Table 2: Payoff Matrix for the Retaliation Game

		North: FDI Controls (FC)	
		No	Yes
South: Quid Pro Quo (QPQ)	Yes	(W_S^{QPQ}, W_N^{QPQ})	$(0, W_N^{FC})$
	No	(W_S^{EC}, W_N^{EC})	(W_S^{EC}, W_N^{EC})

that the South would not abandon quid pro quo, banning outward FDI does not benefit the North due to the losses from FDI profits. In the meanwhile, if the South believes that the North would ban outward FDI, quid pro quo will be abandoned.

5.3 International Cooperation in a Repeated Game

In this subsection, we consider a repeated game. Suppose that time is discrete and goes to infinity and two countries play the game in Table 1 repeatedly each period. The time discounting factor is $\beta \in (0, 1)$. Then the following result holds:

Proposition 8 (Trigger Strategy) *Suppose that the time discounting factor β satisfies:*

$$\frac{\beta}{1-\beta} \geq \frac{w_N^{ES} - w_N^{Free}}{w_N^{Free} - w_N^{QPQ}}. \tag{7}$$

Then the following is a Nash equilibrium: The North does not ban its exports of strategic goods if the South does not impose quid pro quo. If the South once imposes quid pro quo, the North will ban its exports of strategic goods forever. Symmetrically, the South does not impose quid pro quo given the North does not ban its exports of strategic goods. If the North once ban its exports of strategic goods, the South will impose quid pro quo forever.

Proposition 8 characterizes cooperative equilibrium in a repeated game: when both parties are sufficiently patient, the dominant strategy in the static game can be utilized as a threat for deviations from cooperation, which ensures cooperative outcomes in the equilibrium path. While Proposition 8 is a standard application of the Folk Theorem, it figures out the possibility of international cooperation on knowledge sharing which can effectively avoid countries' strategic distortions on trade and FDI.

6 Conclusion

By developing a two-country model with trade and FDI, we characterize the linkages between two nontraditional trade policies, export controls of strategic goods and quid pro quo, and discuss their welfare implications. In this model, the North country has technology advantage and the South country attempts to get an access to advanced technologies. Under certain regularity constraints, two countries are trapped in a prisoner's dilemma in which export controls of strategic goods in the North coexist with quid pro quo in the South. Comparing to the world without intervention, both countries become worse off in the noncooperative equilibrium.

In recent years, globalization has been featured with international knowledge competition and sharing. A country can utilize trade and FDI policies to protect its technology advantage or to get an access to other countries' technologies. However, these policies leads to distortions and thereby efficiency losses. A key insight of this paper is that international cooperation on knowledge sharing could correct these distortions and improve the welfare for all countries. Our model provides theoretical guidelines for recent policy debates and future empirical studies.

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Appendix A Theoretical Results

A.1 Proof to Proposition 1

Proof. The free entry condition in the North implies that

$$\sigma f^e \geq \frac{\left(\frac{2}{T}\right)^{1-\sigma}}{M_N\left(\frac{2}{T}\right)^{1-\sigma}+M_S\left(\frac{\tau(1+t)}{T}\right)^{1-\sigma}}\alpha L+\frac{\left(\frac{2\tau}{T}\right)^{1-\sigma}}{M_N\left(\frac{2\tau}{T}\right)^{1-\sigma}+M_S\left(\frac{1+t}{T}\right)^{1-\sigma}}\alpha L, \tag{8}$$

where the equality holds when $M_N > 0$. Similarly, the free entry condition in the South implies that

$$\sigma f^e \geq \frac{\left(\frac{1+t}{T}\right)^{1-\sigma}}{M_S\left(\frac{1+t}{T}\right)^{1-\sigma}+M_N\left(\frac{2\tau}{T}\right)^{1-\sigma}}\alpha L+\frac{\left(\frac{\tau(1+t)}{T}\right)^{1-\sigma}}{M_S\left(\frac{\tau(1+t)}{T}\right)^{1-\sigma}+M_N\left(\frac{2}{T}\right)^{1-\sigma}}\alpha L, \tag{9}$$

where the equality holds when $M_S > 0$.

Notice that $M_N = M_S = 0$ cannot be an equilibrium. We first consider the case where $M_N > 0$ and $M_S = 0$. In this case, we have

$$M_N = \frac{2\alpha L}{\sigma f^e}. \tag{10}$$

Inserting M_N into Equation (9), Equation (9) holds if and only if

$$t \geq 2\left(\frac{\tau^{\sigma-1}+\tau^{1-\sigma}}{2}\right)^{\frac{1}{\sigma-1}} - 1. \tag{11}$$

When Equation (11) holds, the equilibrium welfare can be expressed as

$$\begin{aligned} W_N &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}}\left(\frac{T}{2}\right)^{\alpha} 2^{\frac{\alpha}{\sigma-1}}, \\ W_S &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}}\left(\frac{T}{2}\right)^{\alpha}\left(2\tau^{1-\sigma}\right)^{\frac{\alpha}{\sigma-1}}. \end{aligned} \tag{12}$$

Therefore, when Equation (11) holds, welfare does not depend on t. Similarly, we can show that $M_N = 0$ and $M_S > 0$ is not an equilibrium once $t \geq 1$. Finally, we consider the case where $M_N > 0$ and $M_S > 0$. This will be an equilibrium only if $1 \leq t < 2\left(\frac{\tau^{\sigma-1}+\tau^{1-\sigma}}{2}\right)^{\frac{1}{\sigma-1}} - 1$.

By the definition of welfare, we have

$$
\begin{aligned}
W_N^{\frac{1-\sigma}{\alpha}} + \tau^{1-\sigma} W_S^{\frac{1-\sigma}{\alpha}} &= \frac{\sigma f^e}{\alpha L} T^{1-\sigma} 2^{\sigma-1}, \\
\tau^{1-\sigma} W_N^{\frac{1-\sigma}{\alpha}} + W_S^{\frac{1-\sigma}{\alpha}} &= \frac{\sigma f^e}{\alpha L} T^{1-\sigma} (1+t)^{\sigma-1}.
\end{aligned} \tag{13}
$$

Then the welfare can be expressed as

$$
\begin{aligned}
W_N &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} \left(\frac{T}{2}\right)^{\alpha} \left(1+\tau^{1-\sigma}\right)^{\frac{\alpha}{\sigma-1}} \left[\frac{1-\tau^{1-\sigma}}{1-\left(\frac{1+t}{2}\right)^{\sigma-1}\tau^{1-\sigma}}\right]^{\frac{\alpha}{\sigma-1}}, \\
W_S &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} \left(\frac{T}{2}\right)^{\alpha} \left(1+\tau^{1-\sigma}\right)^{\frac{\alpha}{\sigma-1}} \left[\frac{1-\tau^{1-\sigma}}{\left(\frac{1+t}{2}\right)^{\sigma-1}-\tau^{1-\sigma}}\right]^{\frac{\alpha}{\sigma-1}}.
\end{aligned} \tag{14}
$$

So W_N is increasing with respect to t when $1 \leq t < 2\left(\frac{\tau^{\sigma-1}+\tau^{1-\sigma}}{2}\right)^{\frac{1}{\sigma-1}} - 1$. ∎

A.2 CES production function of strategic goods and labor

Consider a CES production function of labor and strategic goods:

$$
Q_i^H = T\left[\frac{1}{2} L_i^{\frac{\mu-1}{\mu}} + \frac{1}{2} H_i^{\frac{\mu-1}{\mu}}\right]^{\frac{\mu}{\mu-1}}, \quad \mu \geq 0. \tag{15}
$$

The free entry conditions are then

$$
\sigma f^e \geq \frac{\left(\frac{1}{T}\right)^{1-\sigma}}{M_N\left(\frac{1}{T}\right)^{1-\sigma} + M_S\left(\frac{\tau\left(\frac{1}{2}+\frac{1}{2}t^{1-\mu}\right)^{\frac{1}{1-\mu}}}{T}\right)^{1-\sigma}}\alpha L + \frac{\left(\frac{\tau}{T}\right)^{1-\sigma}}{M_N\left(\frac{\tau}{T}\right)^{1-\sigma} + M_S\left(\frac{\left(\frac{1}{2}+\frac{1}{2}t^{1-\mu}\right)^{\frac{1}{1-\mu}}}{T}\right)^{1-\sigma}}\alpha L, \tag{16}
$$

where the equality holds when $M_N > 0$.

$$
\sigma f^e \geq \frac{\left(\frac{\left(\frac{1}{2}+\frac{1}{2}t^{1-\mu}\right)^{\frac{1}{1-\mu}}}{T}\right)^{1-\sigma}}{M_S\left(\frac{\left(\frac{1}{2}+\frac{1}{2}t^{1-\mu}\right)^{\frac{1}{1-\mu}}}{T}\right)^{1-\sigma} + M_N\left(\frac{\tau}{T}\right)^{1-\sigma}}\alpha L + \frac{\left(\frac{\tau\left(\frac{1}{2}+\frac{1}{2}t^{1-\mu}\right)^{\frac{1}{1-\mu}}}{T}\right)^{1-\sigma}}{M_S\left(\frac{\tau\left(\frac{1}{2}+\frac{1}{2}t^{1-\mu}\right)^{\frac{1}{1-\mu}}}{T}\right)^{1-\sigma} + M_N\left(\frac{1}{T}\right)^{1-\sigma}}\alpha L, \tag{17}
$$

where the equality holds when $M_S > 0$.

We consider the case where $M_N > 0$ and $M_S = 0$. In this case, we have

$$M_N = \frac{2\alpha L}{\sigma f^e}. \tag{18}$$

Then the free entry in the South holds if and only if:

$$t \geq \left[2\left(\frac{\tau^{\sigma-1}+\tau^{1-\sigma}}{2}\right)^{\frac{1-\mu}{\sigma-1}} - 1\right]^{\frac{1}{1-\mu}}. \tag{19}$$

When Equation (19) holds, the equilibrium welfare can be expressed as

$$\begin{aligned} W_N &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} T^{\alpha} 2^{\frac{\alpha}{\sigma-1}}, \\ W_S &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} T^{\alpha} \left(2\tau^{1-\sigma}\right)^{\frac{\alpha}{\sigma-1}}. \end{aligned} \tag{20}$$

we consider the case where $M_N > 0$ and $M_S > 0$. This will be an equilibrium only if $1 \leq t < \left[2\left(\frac{\tau^{\sigma-1}+\tau^{1-\sigma}}{2}\right)^{\frac{1-\mu}{\sigma-1}} - 1\right]^{\frac{1}{1-\mu}}$.

By the definition of welfare, we have

$$\begin{aligned} W_N^{\frac{1-\sigma}{\alpha}} + \tau^{1-\sigma} W_S^{\frac{1-\sigma}{\alpha}} &= \frac{\sigma f^e}{\alpha L} T^{1-\sigma}, \\ \tau^{1-\sigma} W_N^{\frac{1-\sigma}{\alpha}} + W_S^{\frac{1-\sigma}{\alpha}} &= \frac{\sigma f^e}{\alpha L} T^{1-\sigma} \left(\frac{1}{2} + \frac{1}{2} t^{1-\mu}\right)^{\frac{\sigma-1}{1-\mu}}. \end{aligned} \tag{21}$$

Then the welfare can be expressed as

$$\begin{aligned} W_N &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} T^{\alpha} \left(1+\tau^{1-\sigma}\right)^{\frac{\alpha}{\sigma-1}} \left[\frac{1-\tau^{1-\sigma}}{1-\left(\frac{1}{2}+\frac{1}{2}t^{1-\mu}\right)^{\frac{\sigma-1}{1-\mu}} \tau^{1-\sigma}}\right]^{\frac{\alpha}{\sigma-1}}, \\ W_S &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} T^{\alpha} \left(1+\tau^{1-\sigma}\right)^{\frac{\alpha}{\sigma-1}} \left[\frac{1-\tau^{1-\sigma}}{\left(\frac{1}{2}+\frac{1}{2}t^{1-\mu}\right)^{\frac{\sigma-1}{1-\mu}} - \tau^{1-\sigma}}\right]^{\frac{\alpha}{\sigma-1}}. \end{aligned} \tag{22}$$

So W_N is increasing with respect to t when $1 \leq t < \left[2\left(\frac{\tau^{\sigma-1}+\tau^{1-\sigma}}{2}\right)^{\frac{1-\mu}{\sigma-1}} - 1\right]^{\frac{1}{1-\mu}}$. Therefore, the insights of Proposition 1 and 2 hold under the general CES production function of labor and strategic goods.

A.3 Proof to Proposition 4

Proof. Suppose that under export controls, the South sends a take-it-or-leave-it offer to the North firms: they are allowed to produce and make sales in the South if and only if they transfer technologies to the South firms. We assume that the North firms accept the offer and will verify this assumption later.

Since the strategy good is not available to the South, technology 2 will be transfered. Then free entry implies that

$$\begin{aligned} \sigma f^e &\geq \frac{\left(\frac{2}{T}\right)^{1-\sigma}}{M_N\left(\frac{2}{T}\right)^{1-\sigma}+M_S\tau^{1-\sigma}}\alpha L+\frac{\gamma^{1-\sigma}}{M_N\gamma^{1-\sigma}+M_S}\alpha L, \\ \sigma f^e &\geq \frac{\tau^{1-\sigma}}{M_S\tau^{1-\sigma}+M_N\left(\frac{2}{T}\right)^{1-\sigma}}\alpha L+\frac{1}{M_S+M_N\gamma^{1-\sigma}}\alpha L. \end{aligned} \tag{23}$$

If $2-\tau^{\sigma-1}\left(\frac{T}{2}\right)^{\sigma-1}<\gamma^{1-\sigma}<\frac{1}{2-\tau^{1-\sigma}\left(\frac{T}{2}\right)^{1-\sigma}}$, then $M_S>0$ and $M_N>0$ in the equilibrium. Then the welfare can be expressed as

$$\begin{aligned} W_N^{QPQ} &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}}\left[\frac{\left(\frac{T}{2}\right)^{\sigma-1}-\tau^{1-\sigma}\gamma^{1-\sigma}}{1-\gamma^{1-\sigma}}\right]^{\frac{\alpha}{\sigma-1}}, \\ W_S^{QPQ} &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}}\left[\frac{\left(\frac{T}{2}\right)^{\sigma-1}-\tau^{1-\sigma}\gamma^{1-\sigma}}{\left(\frac{T}{2}\right)^{\sigma-1}-\tau^{1-\sigma}}\right]^{\frac{\alpha}{\sigma-1}}. \end{aligned} \tag{24}$$

If $\gamma>\tau$, then $W_N^{Free}>W_N^{QPQ}$.

Now we compute $\left(W_N^{FDI},W_S^{FDI}\right)$. If the North does not ban the exports of strategic goods, then the free entry conditions under the South's import restriction and quid pro quo are

$$\begin{aligned} \sigma f^e &\geq \frac{\left(\frac{2}{T}\right)^{1-\sigma}}{M_N\left(\frac{2}{T}\right)^{1-\sigma}+M_S\left(\frac{2}{T}\right)^{1-\sigma}\tau^{1-\sigma}}\alpha L+\frac{\left(\frac{2}{T}\right)^{1-\sigma}\gamma^{1-\sigma}}{M_N\left(\frac{2}{T}\right)^{1-\sigma}\gamma^{1-\sigma}+M_S\left(\frac{2}{T}\right)^{1-\sigma}}\alpha L, \\ \sigma f^e &\geq \frac{\left(\frac{2}{T}\right)^{1-\sigma}\tau^{1-\sigma}}{M_S\left(\frac{2}{T}\right)^{1-\sigma}\tau^{1-\sigma}+M_N\left(\frac{2}{T}\right)^{1-\sigma}}\alpha L+\frac{\left(\frac{2}{T}\right)^{1-\sigma}}{M_S\left(\frac{2}{T}\right)^{1-\sigma}+M_N\left(\frac{2}{T}\right)^{1-\sigma}\gamma^{1-\sigma}}\alpha L. \end{aligned} \tag{25}$$

Therefore,

$$\begin{aligned} W_N^{FDI} &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}}\left(\frac{T}{2}\right)^{\alpha}\left[\frac{1-\tau^{1-\sigma}\gamma^{1-\sigma}}{1-\gamma^{1-\sigma}}\right]^{\frac{\alpha}{\sigma-1}}, \\ W_S^{FDI} &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}}\left(\frac{T}{2}\right)^{\alpha}\left[\frac{1-\tau^{1-\sigma}\gamma^{1-\sigma}}{1-\tau^{1-\sigma}}\right]^{\frac{\alpha}{\sigma-1}}. \end{aligned} \tag{26}$$

As long as $T > 2$, we have $W_N^{QPQ} > W_N^{FDI}$.

If $2 < \frac{\tau^{\sigma-1} - \gamma^{1-\sigma}\left(\frac{T}{2}\right)^{1-\sigma}}{\left(\frac{T}{2}\right)^{1-\sigma} - \tau^{1-\sigma}} < \tau^{\sigma-1} + 1$, then $W_S^{EC} < W_S^{QPQ} < W_S^{Free}$.

Finally we verify the assumption that the North firms accept the South's offer of "market for technologies". Notice that the firm's profit is proportional to welfare. So the North firms will accept the offer if and only if

$$W_N^{QPQ} \geq \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} \left(\frac{T}{2}\right)^{\alpha}, \tag{27}$$

which holds if and only if $\left(\frac{T}{2}\right)^{\sigma-1} \geq \tau^{1-\sigma}$. ■

A.4 Proof to Proposition 6

Proof. Suppose that the South does not abandon quid pro quo and the North bans its manufacturing imports. Then from Equation (24), we have

$$\begin{aligned} W_N^{RT} &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} \left[\frac{\left(\frac{T}{2}\right)^{\sigma-1}}{1-\gamma^{1-\sigma}}\right]^{\frac{\alpha}{\sigma-1}}, \\ W_S^{RT} &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}}. \end{aligned} \tag{28}$$

Therefore, $W_N^{RT} > W_N^{QPQ}$ and $W_S^{RT} < W_S^{QPQ}$. Moreover, since $\tau^{\sigma-1} > 2\left(\frac{T}{2}\right)^{\sigma-1}$, we have $W_S^{RT} > W_S^{EC}$. ■

A.5 Asymmetric Country Size

In this subsection, we discuss the implications of asymmetric country size for our welfare analysis. First, we provide the proof to Corollary 7.

Proof.

Notice that $L = L_N$ and $r = L_S/L_N$. Then

$$\begin{aligned} W_N^{EC} &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} \left(\frac{T}{2}\right)^{\alpha} (1+r)^{\frac{\alpha}{\sigma-1}}, \\ W_S^{EC} &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} \left(\frac{T}{2}\right)^{\alpha} \left[(1+r)\,\tau^{1-\sigma}\right]^{\frac{\alpha}{\sigma-1}}. \end{aligned} \tag{29}$$

If the South does not abandon quid pro quo and the North bans its manufacturing imports, we have

$$
\begin{aligned}
W_N^{RT} &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} \left[\frac{\left(\frac{T}{2}\right)^{\sigma-1}}{1-\gamma^{1-\sigma}}\right]^{\frac{\alpha}{\sigma-1}}, \\
W_S^{RT} &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} r^{\frac{\alpha}{\sigma-1}}.
\end{aligned}
\tag{30}
$$

Therefore, $W_S^{RT} > W_S^{EC}$ if and only if

$$
\tau^{\sigma-1} > \left(\frac{1+r}{r}\right)\left(\frac{T}{2}\right)^{\sigma-1}. \tag{31}
$$

■

What is the welfare under this asymmetric country size if the North does not ban its manufacturing imports? It is straightforward to show that $M_N > 0$ and $M_S > 0$ if and only if $(1+r) - \frac{1}{r}\tau^{\sigma-1}\left(\frac{T}{2}\right)^{\sigma-1} < \gamma^{1-\sigma} < \frac{1}{1+r-\frac{1}{r}\tau^{1-\sigma}\left(\frac{T}{2}\right)^{1-\sigma}}$. The welfare under quid pro quo can be given by

$$
\begin{aligned}
W_N^{QPQ} &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} \left[\frac{\left(\frac{T}{2}\right)^{\sigma-1} - \tau^{1-\sigma}\gamma^{1-\sigma}}{1-\gamma^{1-\sigma}}\right]^{\frac{\alpha}{\sigma-1}}, \\
W_S^{QPQ} &= \left(\frac{\alpha L}{\sigma f^e}\right)^{\frac{\alpha}{\sigma-1}} \left[\frac{\left(\frac{T}{2}\right)^{\sigma-1} - \tau^{1-\sigma}\gamma^{1-\sigma}}{\left(\frac{T}{2}\right)^{\sigma-1} - \tau^{1-\sigma}}\right]^{\frac{\alpha}{\sigma-1}} r^{\frac{\alpha}{\sigma-1}}.
\end{aligned}
\tag{32}
$$

A.6 The North's Restriction on Outward FDI

Notice that $W_N^{QPQ} > W_N^{FC}$ if and only if

$$
\left[\frac{\left(\frac{T}{2}\right)^{\sigma-1} - \tau^{1-\sigma}\gamma^{1-\sigma}}{1-\gamma^{1-\sigma}}\right]^{\frac{\alpha}{\sigma-1}} > \left(\frac{T}{2}\right)^{\alpha}. \tag{33}
$$

This inequality holds once $T > 2$.