(Preliminary, Comments Welcome)

Sustaining Free Trade with Imperfect Private Information about Non-Tariff Barriers

Jee-Hyeong Park
Department of Economics
Wayne State University
June 2002

ABSTRACT

This paper examines the issue of sustaining free trade when countries receive *imperfect private information* about each other's non-tariff barriers. Because the countries can misrepresent their private belief about other countries' protection levels, the punishment scheme to deter deviations from free trade should provide right incentives for the countries to elicit the true private information. This incentive constraint (ICP) restricts the length of punishment phases. If the private information is *almost perfect*, the ICP is not a binding constraint for symmetric countries in sustaining symmetric cooperation. However, the ICP does become a binding constraint if there exists a large enough asymmetry in the countries' incentives to deviate from free trade, or if there exists a large enough asymmetry in the transparency of countries' trade policies. Then, a mechanism that publicizes the information about non-tariff barriers, like Trade Policy Review Mechanism (TPRM) of WTO, can play a positive role in restoring cooperation by relaxing the ICP.

Corresponding Author: Address: Department of Economics, Wayne State University, Detroit, MI 48202; tel: +1 313 577 2693; fax: +1 313 577 9564; email: jhpark@wayne.edu

JEL Classification Code: F02; F13

Keywords: International Economic Order; Non-tariff Barriers; Imperfect Private Information; Noncooperative game

Acknowledgements: I would like to thank Eric Bond, Yeon-Koo Che, Raymond Deneckere, Robert Staiger and other seminar participants at Pennsylvania State University and University of Wisconsin-Madison for their helpful comments and discussions.

1. Introduction

International cooperation for freer trade like that of the WTO or other various regional trade agreements is often modeled in the context of a repeated game. In Dixit (1987), countries in a repeated relationship support free (or freer) trade based on a trigger strategy that restrains unilateral incentives to deviate from the cooperation by a threat of invoking tariff wars against defections. Bagwell and Staiger (1991) introduce random elements in the volume of trade and show that countries need to have high as well as low protection periods as a cooperative equilibrium to relax higher deviation incentives during high trade volume periods in the repeated game. In these models, countries assume to have perfect information of other countries' protection levels, implying no need for actual exercises of tariff wars in supporting cooperative behaviors.

However, neither the assumption of perfect information nor the implication of no trade dispute are realistic. In contrast to explicit tariff rates, non-tariff barriers (domestic policy variables like tax policies or environmental policies) are not perfectly observable by foreign countries, especially in their effects on the level of protection against imports.[1] In addition, international trade relationships are full of dispute cases, which sometime have leaded to the use of retaliatory measures (often raising tariff levels) against alleged defective behaviors in disputes.

Even in the presence of non-tariff barriers, it is well known that countries can support a certain level of cooperation as long as there exists public information (or a public signal) which is correlated with trade protection levels. The issue of supporting cooperation (or collusion in I.O. literature) with *imperfect public information* has been studied through various papers since the pioneering work by Green and Porter (1984). Riezman (1991) applies the methodology developed by Green and Porter to the problem of supporting freer trade, and shows that countries can support a certain level of cooperation in the presence of non-tariff barriers through an import-trigger strategy,

[1] Countries can always use domestic policies to control protection levels. For example, a 5% tariff can be replicated by a 5% consumption tax along with a 5% production subsidy. In addition, these domestic policies can be carried out in ways that are not easily observable to foreign governments.

which employs periodic trade wars when the amount of imports (a public signal which is negatively correlated with countries' protection levels) is lower than a critical level.

The import-trigger strategy employed in Riezman's analysis or more generally a trigger strategy based on imperfect public information has, however, hardly been utilized in practice.[2] Instead of relying on imperfect public signals like import levels (which are subject to large random effects), countries often try to solve their disputes over non-tariff barriers through a dispute settlement mechanism like that of the GATT, thus employing a third-parties' opinions in settling disputes. For example, 52% of the GATT's 207 trade dispute cases of 1948-1989 periods are about non-tariff barriers.[3]

In these disputes, the problem is not only the degree of errors in observations but also the private nature of the belief (or information) regarding the extensiveness of protection created by non-tariff barriers. Two countries involved in a dispute about non-tariff barriers can have different opinions about the protective effects of a certain policy (due to *imperfect information*) and each country does not know what is the other country's *true* opinion (countries may disguise their opinions intentionally; *private information*). Therefore, to incorporate the reality that the main part of trade disputes are about non-tariff barriers, of which countries may form different private opinions about their protective effects on imports, into the modeling of international trade agreements and the way countries solve trade disputes, I will focus on the analysis of a repeated game with *imperfect private information* of other countries' protection levels.

In contrast to repeated games with imperfect public information of which a series of theoretical works were built up to establish a version of the Folk theorem, there have been relatively little theoretical achievements for the characterization of cooperative equilibria supportable in games with imperfect private information.[4] This is largely due to difficulties in applying the dynamic-programming technique introduced by Abreu, Pearce and Stacchetti (1986, 1990) - often used in characterizing the set of equilibria in repeated

[2] Even though there has been a legislative attempt called the Gephardt Bill of invoking higher tariffs against high bilateral trade deficits in bilateral relationship between the U.S. and Japan, it failed to be included in the U.S. trade bill.
[3] These statistics of the GATT's trade disputes come from Hudec (1993).
[4] See Fudenberg, Levine, and Maskin (1994) for the Folk theorem with imperfect public information.

game with imperfect public information, into the games with imperfect private information. In the case of imperfect public information, players in a repeated game can choose which equilibrium to play depending on the public information in each period. Then, the continuation play will always be an equilibrium after any history of the game, establishing a recursive structure in the repeated game. This enables the use of dynamic-programming methods to this class of repeated games.

However, when players try to support a cooperative equilibrium based on their imperfect private information, the continuation plays will be no longer be equilibria after some history of the repeated game since there exists no public information on which players can condition their actions. To illustrate this point, I use the following simple example: Suppose there exists a trigger strategy of employing private information as a device for invoking punishment phases against possible defections from a cooperative equilibrium that countries try to support. Now, consider a history in which player 1 receives a private signal for invoking a reversionary phase and chooses its action according to its equilibrium strategy. After the history, player 1 computes his belief about the other players' continuation strategies taking its punitive action into account, but the other players compute their beliefs without knowing that player 1 initiated a punishment phase. Thus, the continuation strategies do not constitute any kind of equilibrium after that history. This destroys the recursive structure of the repeated game, and raises serious problem in characterizing the set of equilibria for discounted repeated games with imperfect private information.[5]

To avoid difficulties described above, therefore, analyses on repeated games with imperfect private information typically use some special assumptions like 'epsilon-rationality' by Fudenberg and Levine (1991) or 'no discounting' by Radner (1986) in establishing a version of Folk theorem in their analyses. However, Matsushima (1991) and Bhaskar (1994) derive an 'anti-Folk theorem' on more standard repeated games with private monitoring where players are rational and discount factor is less than one: any pure strategy Nash equilibrium of such games with imperfect private information must be a repetition of the Nash equilibrium of the stage game when players' private signals are

[5] See Kandori and Matsushima (1998) for a more detailed discussion.

independent with each others. This implies that players cannot support any pure strategy equilibrium other than the one-shot Nash even when they have almost perfect private information of other players' actions (note that players' private signals become independent with each others, when their private information become almost perfect).

As a way of escaping from this 'anti-Folk theorem' situation in the repeated game with imperfect private information, Kandori and Matsushima (1998) allow players to communicate about their private information and show that communication is a powerful way of resolving the possible confusion among players in discounted repeated game with private information. In particular, they construct equilibria where players voluntarily communicate what they have observed and prove folk theorem. For a repeated prisoner's dilemma satisfying certain assumption regarding stage game payoffs, Sekiguchi (1997) shows that there exists a nearly efficient sequential equilibrium where players employ mixed strategies, provided that imperfectness of signal is small and players are patient.

Different from these former models relying either on an extensive communication scheme between non-cooperative players or on mixed strategies in supporting cooperative equilibria, I introduces an alternative way of resolving possible confusion among countries in a discounted repeated game with imperfect private information of other countries' protection levels. I allow countries to impose 'explicit tariff rates' (which is perfectly observable to all countries in trade) as well as non-tariff barriers in deciding their protection levels. Then, I can set up a trigger strategy where countries invoke certain periods of tariff war by raising "explicit tariff rates" when they receives private signals having high correlation with other countries' defective behaviors. By employing this explicit tariff war against possible deviations from a cooperative equilibrium, countries can avoid the potential confusion in punishment phase. This induces the "recursive" structure in the repeated game along the equilibrium path (where countries do not deviate from the trigger strategy), enabling the use of dynamic-programming technique originated from Green and Porter (1984).

Due to the private nature of the information to be used as a triggering device, however, there is possibly a serious constraint in employing such a trigger strategy with explicit tariff wars. Since countries can misrepresent their *private* belief (information) of the effect of other countries' non-tariff barriers, the trigger strategy should be designed to provide just the right incentive for countries to truthfully reveal their private information. This requires that the gains from starting a tariff war should be equal to those of not-starting it for the country deciding on whether or not to initiate a tariff war.

I can explain this constraint as follows. First, assume that a cooperative equilibrium can be supported by a trigger strategy (pure strategy) using private information about other countries' protection levels as a triggering device. Then, by definition, no countries will have an incentive to deviate from the equilibrium in the initial period of the game, implying that the private signals in the second period of the game does not carry any significant information of countries' possible defections. Thus, if invoking a tariff war gives lower (higher) expected discounted payoffs than the case of not invoking a tariff war, countries will not (always) invoke a tariff war regardless of private signals they receive in the second period of the game. This in turn makes deviations in the first period to be the optimal behavior, yielding contradiction.

Therefore, to use private information as a device for invoking tariff wars against possible defections from an agreement, the expected payoff of initiating a tariff war needs to be equal to the expected payoff of not-initiating it for the country deciding weather to start a tariff war or not. This restriction from the private nature of information is modeled into the Incentive Constraints for Truthful Revelation of Private Information (ICP) on the trigger strategy specified in Section 2.

Since the ICPs restrict the lengths of tariff wars to be invoked against possible defections, it seems that they may significantly weaken the punishment power against defections, thus, being a restrictive factor in supporting cooperation. With almost perfect private information about others' protection, however, the analysis shows that symmetric countries can support any level of symmetric cooperation sustainable under perfect information through a threat of permanent reversion to Nash tariff wars against deviations (Proposition 1). Thus, the ICPs, (or equivalently, the private nature of information) may not be a binding constraint for such countries to support freer trade, as long as the private information enables them to have very accurate (almost perfect) signals about protective effects of others' policies.[6]

However, when I relax the symmetric country assumption, countries may suffer from the private nature of their information of others' protection levels: the ICPs become binding constraints in supporting a cooperative equilibrium. An example in Section 4.1 shows that the ICPs can become binding constraints in the presence of asymmetry in countries' incentive to sustain freer trade: one country gets more from freer trade and gets less from defecting from it than the other country. Then, the country with a higher incentive to sustain freer trade will be less willing to break it by initiating a tariff war than the other. This reduces the credibility of severe punishments (the ICP decreases number periods that tariff wars can be played) against defections of the country with a lower incentive to sustain freer trade, failing to provide it an enough incentive to sustain the cooperative behavior.

When the ICPs are binding constraints in supporting a cooperative equilibrium, a dispute settlement procedure (which gathers and disseminates information about countries' possible defections) may play a positive role of relaxing the ICPs, thus restoring the cooperative equilibrium by *publicizing* the private information of protective effects of non-tariff barriers. It is often argued that asymmetry in countries' incentives to sustain freer trade exists in trade between countries of asymmetric size. In this regard, my analysis implies a potential role of disputes settlement procedures like that of the GATT may be playing: Strengthening the small countries' punishment powers against large countries' use of non-tariff barriers, thus helping them to support freer trade which would otherwise not be sustainable in the presence of non-tariff barriers.

Countries of asymmetric sizes, however, may not necessarily have asymmetric incentives in sustaining free (or freer) trade when the small country provides side

[6] Even though, my analysis focuses on the issue of supporting freer trade with imperfect private information, this result is applicable to a wider range of repeated prisoner's dilemma situations where players' deviation can either take a form of unobservable actions or take a form of observable actions: for example, Stigler's (1964) "secret price cutting" firms can either cut their prices secretly or cut their prices in obvious ways. In that case, signaling the initiation of punishment phases against possible defections through "obvious" defective behaviors from a tacit collusion, may play a crucial role in escaping from the anti-Folk theorem situation in repeated games with imperfect private information.

payments to the large country as a price for freer trade, as discussed in Park (2000). Then, as shown in Section 4.2, the ICPs may not necessarily be binding constraints in supporting free trade agreements between countries of asymmetric size (Proposition 2). Even though relaxing the ICPs by introducing dispute settlement procedures does expand the set of possible cooperation, the main effect of the ICPs on the cooperative equilibria sustainable between countries of asymmetric size is the elimination of those where most of the gains from cooperation goes to one country at the expense of the other country. Therefore, relaxing the ICPs is not necessarily a mutually beneficial option in this case. At the same time, there exists no strong ground for generally claiming that the relaxation of the ICPs (through dispute settlement procedures) will favor one country at the expense of the other (Proposition 3).

There exists another interesting case where the ICPs can become binding constraints for countries to support freer trade other than the case of asymmetrically sized countries. Section 5 provides a simple example where one country can control its import protection levels through either non-tariff barriers or explicit tariff rates but the other country can control its protection levels only through explicit tariff rates. Thus, this example represents the case where there exists a large asymmetry in the transparency of countries' trade policies.

Then, I can show that the constraint that the ICP imposes on the trigger strategy can easily become restrictive in supporting a cooperative equilibrium between these countries as the degree of noise in the private information increases (or equivalently, the transparency of one county's trade policies decreases due to the intensive use of non-tariff barriers). Therefore, the existence of a large asymmetry in transparency of trade policies among countries may necessitate a dispute settlement procedure like that of the GATT to strengthen the credibility of severe punishments against the use of non-tariff barriers.

The paper is organized as follows. Section 2 develops a bilateral model of trade in the presence of non-tariff barriers, and introduces a simple trigger strategy based on countries' private information together with the conditions for this strategy to be supported as the Nash equilibrium of the repeated game with imperfect private information. Then, Section 3 analyzes the case where countries have almost perfect private information of other countries' protection levels, and provides the benchmark result for symmetric countries' supporting symmetric equilibria. Sustaining the assumption of almost perfect private information, then Section 4 introduces asymmetry into countries involved in trade, and show that the ICPs can be binding constraints in supporting freer trade. On the other hand, Section 5 provides another case where the benchmark result does not hold: the presence of large asymmetry in the transparency of trade policies. Finally, concluding remarks are given in the last section.

2. Model

2.1. Modeling Bilateral Trade with Non-Tariff Barriers

The basic set-up follows Riezman (1991). Assume there exist two countries (home and foreign) producing and trading two products, x and y under perfect competition. The home country imports x and the foreign country imports y. Each country can control protection levels on imports, either through imposing explicit tariffs or through non-tariff barriers. Different from explicit tariffs, the effect of non-tariff barriers on protection level is assumed to be only perfectly known to the country which imposes those barriers but not perfectly known to the other country. Denote the import protection level of the home country by τ and that of the foreign country by τ^* (an asterisk denotes the foreign country's variables). Then, the local prices, p_x, p_y, p_x^*, and p_y^* are related as follows:

$$p_x = p_x^*(1+\tau), \quad p_y^* = p_y(1+\tau^*).$$

Given the assumption of perfect competition, I can define each country's social welfare function as a function of terms of trade, $\pi\ (= p_x^* / p_y)$ and its own protection levels, denoted by $w(\pi,\tau)$ and $w^*(\pi,\tau^*)$, which in turn induce import demand functions, $m(\pi,\tau)$ and $m^*(\pi,\tau^*)$. If there exists no uncertainty (random elements) in this world, implying that the amounts of imports are deterministic functions of each country's protection levels and the term of trade (following $m(\pi, \tau)$ and $m^*(\pi, \tau^*)$), countries may figure out the exact levels of other countries' protections based on information about the terms of trade and the amount of imports, even in the presence of non-tariff barriers.

However, when I introduce uncertainty into the model as a way of representing shocks to technology or preferences, the exact derivation of other countries' protection levels may not be possible. Uncertainty caused by random shocks can be modeled into random components in countries' import demand functions as follows:

(1) $$m_t = m(\pi_t, \tau_t, \psi_t) \text{ and } m_t^* = m^*(\pi_t, \tau_t^*, \psi_t^*),$$

where ψ_t and ψ_t^* respectively denote the random components affecting these home and foreign countries' import demands at period t, (subscript t denotes that variables are of period t).

Then in equilibrium, the following balance of payment condition should be satisfied:

(2) $$\pi_t \cdot m(\pi_t, \tau_t, \psi_t) = m^*(\pi_t, \tau_t^*, \psi_t^*).$$

Using the condition in (2), I can represent the equilibrium values for π_t, m_t, and m_t^* as functions of τ_t, τ_t^*, ψ_t, and ψ_t^*. Thus, the social welfare functions of each country can be written as

$$u(\tau_t, \tau_t^*, \psi_t, \psi_t^*) = w\left(\pi_t(\tau_t, \tau_t^*, \psi_t, \psi_t^*), \tau_t\right), \text{ and}$$
$$u^*(\tau_t^*, \tau_t, \psi_t, \psi_t^*) = w^*\left(\pi_t(\tau_t, \tau_t^*, \psi_t, \psi_t^*), \tau_t^*\right).$$

Given the above payoff functions, I assume that the home country's government maximizes its present discounted expected social welfare function by choosing its stream of protection levels $T = (\tau_o, \tau_1, \tau_2, ...)$ given a discount factor, β:

$$\underset{T}{\text{Max}} \sum_{t=0}^{\infty} \beta^t \cdot Eu(\tau_t, \tau_t^*, \psi_t, \psi_t^*),$$

and similarly for the foreign country's government.

By assuming the Marshall-Lerner condition (the sum of the elasticities of import demands exceeds 1) together with lump-sum redistribution of tariff revenues to consumers, I can establish that countries improve their terms of trade by unilaterally raising their protection levels on imports.[7] Finally, I can show that each country improves its own welfare levels by unilaterally raising the protection levels by a small amount from zero protection, which then harms the other country.

For the sequence of moves, I assume that countries set their import protection levels simultaneously in each period of the repeated game before they trade with each other. Then, in a one-shot tariff setting game (or equivalently $\beta = 0$ case in the above repeated game), the static Nash protection levels of each country, denoted by h and h^*, will be higher than zero protection. Therefore, as long as the countries' abilities to change the terms of trade through imposing import protections are similar to each other, the one-shot Nash equilibrium yields a prisoner's dilemma situation where countries' expected levels of welfare under the one-shot Nash equilibrium are lower than those under free trade, $Eu(h, h^*, \psi_t, \psi_t^*) < Eu(0,0, \psi_t, \psi_t^*)$ and $Eu^*(h^*, h, \psi_t, \psi_t^*) < Eu^*(0,0, \psi_t, \psi_t^*)$.[8]

Therefore, if countries are in a static Nash equilibrium, it is countries' mutual interests to reciprocally lower their protection levels. If protection levels are perfectly observable, countries in a repeated relationship (with $\beta > 0$) can support freer trade than the one-shot Nash equilibrium based on a trigger strategy of invoking a tariff war when

---

[7] In this paper, I will focus on the case where the only route that countries can gain by imposing import protection is through changing the term of trade in their favor. Thus, I am not considering political incentives to impose import protection.

[8] In the presence of a large asymmetry in countries' sizes, it is possible that large countries can get higher welfare levels under a one-shot Nash tariff war with small countries than under free trade. Small countries can hardly change the terms of trade in their favor through imposing import protections. Only large ones can inflict such protections in the one-shot Nash tariff war, thereby potentially winning a tariff war against small countries. However, a mutually beneficial free trade agreement is still possible between countries of asymmetric size by replacing distortional transfers from the large to the small countries (that is large countries' positive tariffs) with non-distortional transfers under free trade. For a detailed analysis on free trade agreements between countries of asymmetric size, see Park (2000),

any deviation occurs from a cooperative equilibrium. In the presence of non-tariff barriers, however, together with random shocks to the economies, countries cannot perfectly observe other countries' protection levels as discussed earlier.

Even though countries cannot observe the exact protection levels of other countries, there exists public information, like the amount of imports, which is correlated with countries' protection levels. For example, Riezman (1991) assumes that the equilibrium value for the home country's imports, m_t can be rewritten as follows:

(3) $$m_t = \theta_t m(\tau_t, \tau_t^*) \left(= m\left(\tau_t, \tau_t^*, \psi_t, \psi_t^*\right)\right)$$

where θ_t is i.i.d. with c.d.f. F_θ and continuous density f_θ, and $E(\theta_t) = 1$.

Then, countries may use the home country's import level, m_t as a *public signal* to invoke tariff wars against possible defections from a cooperative equilibrium: Employing periodic trade wars when m_t becomes less than a critical level of imports, $\overline{m}$. This punishment scheme can mitigate countries' incentives to raise protection levels higher than a cooperative level with, since setting higher protection levels increases the probability of invoking costly trade wars: $\Pr(\theta_t \cdot m(\tau, \tau^*) \le \overline{m})$ is a increasing function in τ and τ^* because $m(\tau, \tau^*)$ is a decreasing function in τ and τ^*. Riezman (1991) shows that countries can support a cooperative equilibrium (lower protection levels than the one-shot Nash protection levels) based on this import trigger strategy.

However, the amount of imports may be subject to non-negligible random shocks, like changes in consumers' preferences or technology shocks, which are represented by θ_t in (3). As the random effects become bigger in determining the amount of imports relative to the effects of import protection levels, the effectiveness of an import trigger strategy in supporting freer trade decreases.[9]

[9] This statement is based on Kandori's (1992) result: Pure strategy sequential equilibrium payoff set, in the general model of imperfect monitoring (with public signals), shrinks when the noise in the signal increases.

Even when the import level cannot work as a sensitive measure for the use of non-tariff barriers due to significant random shocks, countries may still have information about factors which determines the random elements in import demands, with which they can restore some sensitive measure for other countries' protection levels. If the information about these factors is public knowledge, then countries can construct a public measure other than the amount of imports, which can work as a device for triggering tariff wars against possible defections from a cooperative equilibrium. The information about these factors, however, may not be public but private knowledge, thus the sensitive measure to be constructed from this information may also be private information.

2.2. Introducing Private Signals of Other Countries' Protection Levels

To introduce private signals of other countries' protection levels into the model, I assume that the random factor in the home country's import, θ_t in (3) is a function of three random components, ϕ_t, ϕ_t^*, and $\hat{\phi}_t$:

(4) $$\theta_t = \theta(\phi_t, \phi_t^*, \hat{\phi}_t),$$

where $\phi_t \in \Phi$ is only known to the home country at period t+1, $\phi_t^* \in \Phi^*$ is only known to the foreign country at period t+1, and $\hat{\phi}_t \in \hat{\Phi}$ is unknown at any time.[10] In addition, I assume that ϕ_t and ϕ_t^* are informative about θ_t in the sense that $\mathrm{Var}(\theta_t|\phi_t)$ and $\mathrm{Var}(\theta_t|\phi_t^*)$ are lower than $\mathrm{Var}(\theta_t)$ for all ϕ_t and ϕ_t^*. Finally, I assume that

[10] It is important to note that the signals of random factors at period t, ϕ_t and ϕ_t^* are revealed to each country one period later. If ϕ_t and ϕ_t^* were revealed at period t, they would have affected the expected social welfare levels of each country at period t, resulting in changed incentives to impose import protections. This change in timing of availability of private information will make each country's incentive to deviate from a cooperative equilibrium, vary from period to period, depending on revealed private signals about random factors. This raises new issues in enforcing trade agreements, of which I will discuss in Section 6. However, the focus of this paper is to understand the role of *private information about other countries' protection levels* in supporting freer trade between countries, thus I will confine my attention to the case where the private signals do not affect countries' incentives to deviate from an agreement by assuming the private information about ϕ_t and ϕ_t^* to be revealed at period t+1.

$\Pr(\phi_t | \phi_t^*) \neq 0$ and $\Pr(\phi_t^* | \phi_t) \neq 0$ for all $\phi_t \in \Phi$ and $\phi_t^* \in \Phi^*$, which ensures no perfect correlation between countries private signals.

Adding these extra observations to countries' information sets may allow countries to have a "more effective" punishment scheme (which utilizes their private information) than the trigger strategy relying on public signals, against the use of non-tariff barriers. To elaborate this point, I first assume that countries can construct *private signals*, μ_t and μ_t^*, respectively for the home and the foreign country, based on their private information (ϕ_t, ϕ_t^*) and the public signal (m_t):

$$\mu_t = \mu\left[m_t\left(\tau_t, \tau_t^*\right), \phi_t\right] \text{ and } \mu_t^* = \mu^*\left[m_t\left(\tau_t, \tau_t^*\right), \phi_t^*\right],$$

These signals are possibly more sensitive measures of other countries' use of non-tariff barriers than the import levels, m_t.

Then, similar to the trigger strategy used in Riezman (1991) which invokes trade wars when m_t (a public signal) becomes less than a critical import level $\overline{m}$, countries with private signals (μ_t and μ_t^*) can set the corresponding critical levels of private signals at $\overline{\mu}$ and $\overline{\mu}^*$, thereby invoke tariff wars if $\mu_t \leq \overline{\mu}$ or $\mu_t^* \leq \overline{\mu}^*$. This punishment scheme of utilizing private signals can be "more effective" in discouraging defections than that of using m_t, if there exist (μ_t, μ_t^*) and ($\overline{\mu}, \overline{\mu}^*$) such that deviations incur higher probabilities for invoking trade wars:

$$\Pr(\theta_t m(l, \tau^*) \leq \overline{m}) < \Pr(\mu(m(l, \tau^*), \phi_t) \leq \overline{\mu}) \text{ and}$$

$$\Pr(\theta_t m(\tau, l^*) \leq \overline{m}) < \Pr(\mu^*(m(\tau, l^*), \phi_t^*) \leq \overline{\mu}^*) \text{ for all } (\tau, \tau^*) > (l, l^*),$$

and keeping cooperation induces higher probabilities for not invoking trade wars:

$$\Pr(\theta_t \cdot m(l, \tau^*) > \overline{m}) < \Pr(\mu(m(l, \tau^*), \phi_t) > \overline{\mu}) \text{ and}$$

$$\Pr(\theta_t \cdot m(\tau, l^*) > \overline{m}) < \Pr(\mu^*(m(\tau, l^*), \phi_t^*) > \overline{\mu}^*) \text{ for all } (\tau, \tau^*) \leq (l, l^*),$$

where l and l^* denote the cooperative levels of protection to support.[11]

Given there exist μ_t, μ_t^*, $\overline{\mu}$, and $\overline{\mu}^*$ satisfying the above conditions, it is clear that a punishment scheme of utilizing such private signals may improve the welfare of countries compared to using less sensitive measures like the import amount as a device to invoke punishment phases against possible defections. In the rest of the paper, I will explore this potentially beneficial possibility: utilizing a trigger strategy based on private signals in supporting freer trade in the presence of non-tariff barriers.

2.3. Modeling A Trigger Strategy

The trigger strategy to be employed in this paper is similar in structure to that of Riezman (1991), which originates from Green and Porter (1984). Countries try to support cooperative protection levels, (l, l^*) which are lower than the one-shot Nash protection levels, (h, h^*), by threatening to begin a punishment phase involving periods of high protections when countries' private signals exceed certain critical levels. The main difference between the trigger strategy employed here and that of Riezman (1991) is that the triggering devices are *private measures* like countries' private signals, μ_k and μ_k^* instead of a public one like the amount of imports.

When countries try to use these private signals as a device of triggering a trade war against possible defections, the private nature of these signals may raise some issues which do not occur when public information is employed for the same purpose. One problem is in coordinating punishment phases. If one country starts a punishment phase by imposing high protection levels through non-tariff barriers when its private signal become lower than a critical level, then the other country may not know whether a punishment phase has been invoked or not. As discussed in Section 1, this creates the

[11] With almost perfect private information ($\mathrm{Var}(\theta_t | \phi_t)$, $\mathrm{Var}(\theta_t | \phi_t^*) \to 0$), it is easy to show that there exist a punishment scheme of utilizing private signals which satisfies the above conditions. However, generally specifying requirements for private information to satisfy these conditions still needs to be done.

problem that continuation plays are no longer an equilibrium after some history ($\mu_t \le \bar{\mu}$ or $\mu_t^* \le \bar{\mu}^*$) occurs in the repeated game, thus making characterization of the equilibrium set of the repeated game difficult.

To escape from this problem, I assume that countries use explicit tariffs for the punishment purpose, thus signaling the initiation of a punishment phase. As shown later, this restores the "recursive" structure of repeated game where continuation plays are always an equilibrium after any history of the game. This assumption of using explicit tariffs for punishment not only makes the problem tractable but also coincides with the GATT's rule of only allowing explicit measures (in most cases explicit tariffs) for the purpose of retaliation. In addition, the behavior of using explicit tariffs for punishment can be supported as an equilibrium behavior, which I will show later.

Now, denote the strategies employed by the home and the foreign country by s and s^*:

$$
\begin{aligned}
& s = (s_0,\ s_1,\ldots),\ s^* = (s_0^*, s_1^*,\ldots), \\
& s_k = (e_k,\ \tau_k),\ s_k^* = (e_k^*, \tau_k^*),
\end{aligned}
$$

where e_k and e_k^* represent the home and the foreign country's explicit tariff levels in period k of the repeated game, reflecting that countries can choose their total protection levels (τ_k, τ_k^*) not only with non-tariff barriers but also with explicit tariffs. Then, I assume that each country's strategy at period k depends on the history of its private signals of the other country's protection levels and the other country's explicit tariff rates up to period k-1:

$$
\begin{aligned}
& s_k\left[(\mu_0, e_0^*), (\mu_1, e_1^*), \ldots, (\mu_{k-1}, e_{k-1}^*)\right] = (e_k, \tau_k) \\
& s_k^*\left[(\mu_0^*, e_0), (\mu_1^*, e_1), \ldots, (\mu_{k-1}^*, e_{k-1})\right] = (e_k^*, \tau_k^*) \text{ with} \\
& s_0 = (e_0,\ \tau_0),\ s_0^* = (e_0^*, \tau_0^*),
\end{aligned}
$$

where (e_0, τ_0) and (e_0^*, τ_0^*) respectively denote the home and the foreign country's explicit and total protection levels at the initial period of the repeated game.

Then, a trigger strategy can be defined as follows:

(a) At the initial period of the repeated game, countries are supposed to play $(e_0, \tau_0) = (0, l)$ and $(e_0^*, \tau_0^*) = (0, l^*)$.

(b) As long as their private signals are higher than the critical levels ($\mu_k > \bar{\mu}$ and $\mu_k^* > \bar{\mu}^*$) and other countries' explicit protection levels remains at zero, countries are supposed to play $(e_k, \tau_k) = (0, l)$ and $(e_k^*, \tau_k^*) = (0, l^*)$.

(c) When either of the two countries has private signals lower than the critical levels ($\mu_k \leq \bar{\mu}$ or $\mu_k^* \leq \bar{\mu}^*$), then the one with bad signals about the other's cooperation is supposed to start a punishment phase by setting $(e_k, \tau_k) = (h(l^*), h(l^*))$ for the home country and $(e_k^*, \tau_k^*) = (h^*(1), h^*(l))$ for the foreign country, where $h(l^*)$ and $h^*(1)$ respectively denote the home and the foreign country's static optimal tariff rate given the other country follows its specified strategy. [12]

(d) This (an explicit tariff rate higher than zero) will signal the other country that it is now a punishment phase. Then, the countries are supposed to play the one-shot Nash tariff war by setting $(e, \tau) = (h, h)$ and $(e^*, \tau^*) = (h^*, h^*)$ for a predetermined length of periods: T-3 periods if it were invoked by the home country, T'-3 periods if it were invoked by the foreign country, and C-3 periods if it were invoked by both countries at the same time.[13]

(f) Then, in the final period of the punishment phase, countries are supposed to either play $(e, \tau) = (h, h)$ and $(e^*, \tau^*) = (h^*, h^*)$ according to some predetermined probabilities (λ if

[12] In general, $h(l^*)$ is different from the static optimal tariff of the home country given the foreign country's protection level is l^* in the one-shot game, since the foreign country imposes $h^*(l)$ with positive probability ($\Pr(\mu_k^* \leq \bar{\mu}^*) > 0$) even when it follows the specified strategy. A similar argument applies to $h^*(l)$.

[13] Since the private signals are not perfectly correlated with each other by assumption, there exist three kinds of punishment phases: the one initiated by the home country, the one initiated by the foreign country, and the one initiated by the home and foreign country at the same time.

it were invoked by the home country, λ' if it were invoked by the foreign country, or λ^C it were invoked by both countries at the same time) or play $(e,\tau)=(0,l)$ and $(e^*,\tau^*)=(0,l^*)$.[14]

(g) After the end of punishment phases, countries are supposed to restart the game by following the strategy specified from (a) to (f).

Denote the home and the foreign country's strategies defined above by $\bar{s}$ and $\bar{s}^*$, respectively. Then, $[l,l^*,\bar{\mu},\bar{\mu}^*,T,T',C,\lambda,\lambda',\lambda^C]$ characterizes $\bar{s}$ and $\bar{s}^*$.

If countries follows $\bar{s}$ and $\bar{s}^*$, then any period of the repeated game falls into two categories: a cooperative period where both countries choose zero explicit tariff rates (thus, the cooperative protection levels), and a period in any of the three kinds of punishment phases. Therefore, the trigger strategy employed here imposes a certain recursive structure on the repeated game, enabling the use of dynamic programming methods often used in solving repeated games with imperfect public signals. This simplification is generally not possible for the repeated game with imperfect private signals due to the absence of publicly observable signals to coordinate the punishment phases, but is attained here since the countries utilize explicit tariff rates as public signals to coordinate the punishment.

Thus, I can derive expressions for the countries' discounted expected payoff functions along the equilibrium path (where countries follow their specified strategies) as follows. Define $\Pr(l^*)=\Pr(\mu(m(l,l^*),\phi_t)\leq\bar{\mu})$, denoting the probability of a tariff war to be invoked by the home country given the foreign country sets its cooperative protection level at l^*, and define $\Pr^*(l)=\Pr(\mu^*(m(l,l^*),\phi_t^*)\leq\bar{\mu}^*)$, denoting the probability of a tariff war to be invoked by the foreign country given the home country sets its cooperative protection level at l. Then, the discounted expected utility of the home

[14] Employing this strategy enables the punishment phase to be smooth enough to allow the discounted expected payoffs of invoking a punishment phase to be equal to that of not invoking it. The point will be clarified when I discuss the bench mark case of symmetric countries with almost perfect private information.

[foreign] country at the initial period of this repeated game, denoted by $V_0(l)$ [$V_0^*(l^*)$] is:

$$
(5)\quad
\begin{aligned}
V_0(l) &= u(l,l^*) + \left[1-\Pr(l^*)\right]\left\{\left[1-\Pr^*(l)\right]\cdot\beta\cdot V_0(l) + \Pr^*(l)\left[q' + \beta^{T'}\cdot V_0(l)\right]\right\} \\
&+ \Pr(l^*)\left\{\left[1-\Pr^*(l)\right]\cdot\left[q + \beta^{T}\cdot V_0(l)\right] + \Pr^*(l)\left[q^C + \beta^C\cdot V_0(l)\right]\right\} \\
V_0^*(l^*) &= u^*(l^*,l) + \left[1-\Pr^*(l)\right]\left\{\left[1-\Pr(l^*)\right]\cdot\beta\cdot V_0^*(l^*) + \Pr(l^*)\left[q^{*\prime} + \beta^{T}\cdot V_0^*(l^*)\right]\right\} \\
&+ \Pr^*(l)\left\{\left[1-\Pr(l^*)\right]\cdot\left[q^* + \beta^{T'}\cdot V_0^*(l^*)\right] + \Pr(r^*)\left[q^{*C} + \beta^C\cdot V_0^*(l^*)\right]\right\}
\end{aligned}
$$

where

$$
\begin{aligned}
q' &= \beta u(l,h^*(l)) + \beta^2 u(h,h^*) + \cdots + \beta^{T'-2}u(h,h^*) + \beta^{T'-1}\left[\lambda' u(h,h^*) + (1-\lambda')u(l,l^*)\right] \\
q &= \beta u(h(l^*),l^*) + \beta^2 u(h,h^*) + \cdots + \beta^{T-2}u(h,h^*) + \beta^{T-1}\left[\lambda u(h,h^*) + (1-\lambda)u(l,l^*)\right] \\
q^C &= \beta u(h(l^*),h^*(l)) + \beta^2 u(h,h^*) + \cdots + \beta^{C-2}u(h,h^*) + \beta^{C-1}\left[\lambda^C u(h,h^*) + (1-\lambda^C)u(l,l^*)\right]
\end{aligned}
$$

$$
\begin{aligned}
q^{*\prime} &= \beta u^*(l^*,h(l^*)) + \beta^2 u^*(h^*,h) + \cdots + \beta^{T-2}u^*(h^*,h) + \beta^{T-1}\left[\lambda u^*(h^*,h) + (1-\lambda)u^*(l^*,l)\right] \\
q^* &= \beta u^*(h^*(l),l) + \beta^2 u^*(h^*,h) + \cdots + \beta^{T'-2}u^*(h^*,h) + \beta^{T'-1}\left[\lambda' u^*(h^*,h) + (1-\lambda')u^*(l^*,l)\right] \\
q^{*C} &= \beta u^*(h^*(l),h(l^*)) + \beta^2 u^*(h^*,h) + \cdots + \beta^{C-2}u^*(h^*,h) + \beta^{C-1}\left[\lambda^C u^*(h^*,h) + (1-\lambda^C)u^*(l^*,l)\right]
\end{aligned}
$$

with $u(\tau,\tau^*) = Eu(\tau,\tau^*,\psi,\psi^*)$ and $u^*(\tau^*,\tau) = Eu^*(\tau^*,\tau,\psi,\psi^*)$.

Rearranging (5), I can obtain the following expression for the discounted expected utility of the home country at the initial period of the repeated game:

$$
V_0(l) = \frac{u(l,l^*) + \left[1-\Pr\right]\cdot\Pr^*(l)\cdot q' + \Pr\cdot\left[1-\Pr^*(l)\right]\cdot q + \Pr\cdot\Pr^*(l)\cdot q^C}{1-\beta+\left[1-\Pr\right]\cdot\Pr^*(l)\cdot(\beta-\beta^{T'}) + \Pr\cdot\left[1-\Pr^*(r)\right]\cdot(\beta-\beta^{T}) + \Pr\cdot\Pr^*(l)\cdot(\beta-\beta^{C})},
$$

where Pr=Pr(l^*), and a similar expression for $V_0^*(l^*)$.

Note that the recursive structure of the equilibrium path of the trigger strategy ($\bar{s}$ and $\bar{s}^*$) enables this derivation of the discounted expected utility at the initial period of the repeated game. Using similar methods, I can derive the similar expressions for discounted expected utility at any stage of the equilibrium path.

2.4. Defining the equilibrium of the repeated game

In the previous section, I described the trigger strategy to be played between countries in the repeated game. However, I have not defined the conditions that such a strategy can be supported as an equilibrium of the repeated game. As an equilibrium concept for the repeated game, I use the Nash equilibrium.

A Nash equilibrium is a strategy pair $(\hat{s}, \hat{s}^*)$ for which

$$(6) \qquad \underset{\hat{s},\hat{s}^*}{E}\left\{\sum_{t=0}^{\infty}\beta^t u(\hat{s}_t, \hat{s}_t^*, \psi_t, \psi_t^*)\right\} \geq \underset{s,\hat{s}^*}{E}\left\{\sum_{t=0}^{\infty}\beta^t u(s_t, \hat{s}_t^*, \psi_t, \psi_t^*)\right\}$$

for all possible strategies s, with a similar condition for the foreign country. Therefore, the Nash equilibrium requires each country's strategy at any period of the game to assign actions which maximizes its discounted expected payoffs given the other country follows the equilibrium strategy.

There exists one obvious Nash equilibrium strategy pair: $\bar{s}$ and $\bar{s}^*$ with $(l, l^*) = (h, h^*)$ can be supported as a Nash equilibrium of the repeated game, since they assign countries to impose their one-shot Nash protection levels at any period of the game. However, a more interesting equilibrium is the one where countries can support lower protection levels than the one-shot Nash levels, thus realizing the gains from freer trade in a repeated trade relationship. This corresponds to $\bar{s}$ and $\bar{s}^*$ with $(l, l^*) < (h, h^*)$. The focus of my analysis, therefore, is to characterize cooperative protection levels (l, l^*) which are sustainable by the trigger strategy $\bar{s}$ and $\bar{s}^*$ as a Nash equilibrium, or equivalently to characterize $[l, l^*, \bar{\mu}, \bar{\mu}^*, T, T', C, \lambda, \lambda', \lambda^C]$ of $\bar{s}$ and $\bar{s}^*$ which can be supported a Nash equilibrium of the repeated game.

As mentioned earlier, to be supported as a Nash equilibrium, each country in the repeated game should have no unilateral incentive to deviate from its specified strategy at any stage of the repeated game given the other country follows the specified strategy. This requires checking whether each country's discounted payoffs from following the equilibrium path is equal or greater than those from playing any strategy other than the equilibrium one at any stage of the repeated game. In general, repeated games with imperfect private information where there is no recursive structure in the game, it is usually not a feasible task. However, the recursive structure of the equilibrium path generated by $\bar{s}$ and $\bar{s}^*$ makes the task to be rather manageable one, though not completely.[15]

In checking whether or not $\bar{s}$ and $\bar{s}^*$ can be supported as a Nash equilibrium of the repeated game, it is helpful to divide the strategies of any period according to assigned actions. In $\bar{s}$ and $\bar{s}^*$, there are only three kinds of actions to be played for each country at any period of the repeated game: $(e,\tau)=(0,l)$, $(e,\tau)=(h(l^*),h(l^*))$, or $(e,\tau)=(h,h)$ for the home country, and $(e^*,\tau^*)=(0,l^*)$, $(e^*,\tau^*)=(h^*(l),h^*(l))$, or $(e^*,\tau^*)=(h^*,h^*)$ for the foreign country.

Therefore, one way of validating that $\bar{s}$ and $\bar{s}^*$ is a Nash equilibrium, is to show that for each of these three kinds of actions, each country does not have any incentive for choosing other action profiles at any period of the repeated game, given the other country follows its specified strategy. Since $\bar{s}$ and $\bar{s}^*$ have a symmetric structure, I can focus on the incentive constraints for the home country without loss of generality.

First, it is easy to show that the home country has no incentive to choose other actions whenever it is assigned to choose $(e,\tau)=(h,h)$. $\bar{s}$ assigns the home country to choose $(e,\tau)=(h,h)$ from the second to the last period of any punishment phases, where $\bar{s}^*$ assign the foreign country to choose $(e^*,\tau^*)=(h^*,h^*)$. Therefore, whenever the home country is assigned to choose $(e,\tau)=(h,h)$, it is basically assigned to choose its static optimal behavior which maximize its static payoff. Furthermore, choosing actions

---

[15] As discussed later, completing the task of characterizing the subgame perfect equilibrium supported with $\bar{s}$ and $\bar{s}^*$ will be postponed to the next section where countries assumed to have almost perfect private signal of other countries protection levels (thus, the noise level in countries' private signals goes to zero). However, certain progresses are still made in the characterization of the subgame perfect equilibrium even in this section.

other than $(e,\tau)=(h,h)$ does not affect the foreign country's future actions following $\bar{s}^*$. Thus, choosing $(e,\tau)=(h,h)$ is indeed an action which maximizes the expected discounted payoff of the home country whenever it is assigned to choose that action.

Now, the cases of $(e,\tau)=(0,l)$ and $(e,\tau)=(h(l^*),h(l^*))$ remain to be checked for validating $\bar{s}$ to be a Nash equilibrium of the repeated game. $(e,\tau)=(0,l)$ is the action that countries try to support as a cooperative behavior. $(e,\tau)=(h(l^*),h(l^*))$ is an action that the home country is supposed to follow when it initiates a punishment phase against possible defections. Since countries try to support the cooperative behavior by the threat of invoking a punishment phase, it is natural to first specify the conditions that the action $(e,\tau)=(h(l^*),h(l^*))$ of initiating a punishment phase is to be supported as an equilibrium behavior, and then check whether $(e,\tau)=(0,l)$ can be supported as an equilibrium action or not, given those conditions are met.

$\bar{s}$ assigns the home country to set $(e,\tau)=(h(l^*),h(l^*))$ at period k, if period k-1 were a cooperative period (where countries explicit protection levels are zero) and $\mu_k \leq \bar{\mu}$. Since $h(l^*)$ is the static optimal tariff rate given that the foreign country follows $\bar{s}^*$, the home country has no incentive to deviate from this specified action if it is only concerned about the current payoff. However, this action will invoke a punishment phase where countries play costly tariff wars for a certain number of periods. Furthermore, μ_k is a private signal only observable to the home country, thus it can ignore its private signal without informing the foreign country. Therefore, to support $(e,\tau)=(h(l^*),h(l^*))$ as an equilibrium action, the expected discounted payoff of initiating a punishment phase must be equal to that of not initiating a punishment phase for the home country. Similarly, to support $(e^*,\tau^*)=(h^*(l),h^*(l))$ as an equilibrium action, the same condition should be met for the foreign country. These constraints are formalized as the following Incentive Constraints for Truthful Revelation of Private Information (**ICPs**) with **ICPh** for the home country and **ICPf** for the foreign country:

ICPs:

(7)

< ICPh >

$$\left[1-\Pr^{*}(l)\right]\cdot\beta\cdot V_{0}(l)+\Pr^{*}(l)\left[q'+\beta^{T'}\cdot V_{0}(l)\right]=$$

$$\left[1-\Pr^{*}(l)\right]\cdot\left[q+\beta^{T}\cdot V_{0}(l)\right]+\Pr^{*}(l)\left[q^{C}+\beta^{C}\cdot V_{0}(l)\right]$$

< ICPf >

$$\left[1-\Pr(l^{*})\right]\cdot\beta\cdot V_{0}^{*}(l^{*})+\Pr(l^{*})\left[q^{*}'+\beta^{T}\cdot V_{0}^{*}(l)\right]=$$

$$\left[1-\Pr(l^{*})\right]\cdot\left[q^{*}+\beta^{T'}\cdot V_{0}^{*}(l^{*})\right]+\Pr(l^{*})\left[q^{*C}+\beta^{C}\cdot V_{0}^{*}(l^{*})\right]$$

where all the notations have the same definitions as in (5): $V_0(l)$ and $V_0^*(l^*)$ respectively denote the home and the foreign country's discounted expected payoffs at the initial period of the repeated game from following $\bar{s}$ and $\bar{s}^*$.

The first equality is the ICP for the home country (**ICPh**) such that the expected payoff of invoking a punishment phase in the second period (the left side of the equality) is equal to the expected payoff of not invoking it in the second period (the right side of the equality), and similarly for the second equality as the ICP for the foreign country (**ICPf**). However, it is important to note that the equilibrium path to be followed from period k is identical to that for period j, as long as period k-1 and period j-1 are both a cooperative period. Therefore, the ICPs in (7) apply not only to the second period of the repeated game, but also to any period where an initiation of punishment can be considered (meaning that the previous period was a normal one).

The primary function of above ICPs is balancing the gains from initiating a punishment phase (by imposing its static optimal tariff) with the losses from following periods of tariff wars by restricting the length of punishment phases. I can clarify this point by focusing on the case where countries have very sensitive signals of other countries' defections. By assuming $\Pr(l^*)\rightarrow 0$ and $\Pr^*(l)\rightarrow 0$, I can simplify the ICPs in (7) into:

(7')

<u>ICPh</u>: $V(l) = q/(\beta-\beta^{T})$

<u>ICPf</u>: $V^*(l^*) = q^*/(\beta-\beta^{T'})$.

Note that the right sides of the ICPh and ICPf in (7'), $q/(\beta-\beta^{T})$ and $q^{*}/(\beta-\beta^{T'})$ are decreasing functions of T and T', respectively. On the other hand, the left sides of the above ICPs can be treated as constant terms against changes in T and T' due to the assumption of $\Pr(l^{*})\rightarrow 0$ and $\Pr^{*}(l)\rightarrow 0$. Thus, the ICPh restricts the length of a punishment phase to be invoked by the home country against possible defections of the foreign country (T), and similarly the ICPf restricts T'.

Given that $[T, T', C, \lambda, \lambda', \lambda^{C}]$ of $\bar{s}$ and $\bar{s}^{*}$ satisfy ICPs in (7), for validating that $\bar{s}$ and $\bar{s}^{*}$ can be supported as a equilibrium strategy, now it is only remained to be checked whether $(e_0, \tau_0) = (0, l)$ and $(e_0^{*}, \tau_0^{*}) = (0, l^{*})$ can be supported as cooperative behaviors of the repeated game. To support these cooperative actions as equilibrium behaviors, there should be no incentives for each country to take other actions given the other country follow its specified strategy.

However, no attempt is made here to specify incentive constraints which prevent deviations from the cooperative equilibrium, since characterization of an optimal deviation strategy, given a punishment scheme, is difficult when there are errors in observations. In contrast to a perfect information case, when a country devises an optimal way to defect, it must decide not only the protections levels for the first period of the defection, but also those levels for the following periods, since its initial defections may not be detected by the other country. Furthermore, the probability of a punishment phase to be invoked, after the initial defection, would be different from those probabilities following defections in subsequent periods.

If countries' private information become more accurate (thus, the probability of not being detected on their initial defection decreases), however, the importance of optimizing defections to follow after an initial one will decrease in countries' decision on their initial defection levels. In particular, countries' initial optimal defection levels constrained by their dynamic consideration for the following defection path will converge to the countries' static optimal defection levels, as the noise in countries' private information goes to zero. Thus, the incentive constraints for supporting cooperative behaviors as an equilibrium can be easily specified in the following section, where I assume that countries have *almost perfect private information* of other countries protection levels.

In this section, I try to characterize $[l, l^*, \bar{\mu}, \bar{\mu}^*, T, T', C, \lambda, \lambda', \lambda^C]$ of $\bar{s}$ and $\bar{s}^*$ which can be supported as a Nash equilibrium of this repeated game with imperfect private information. It has been shown that countries can employ a trigger strategy of employing private signals as a punishment invoking device against possible defections as long as the ICPs in (7) are satisfied. However, the ICPs restrict the lengths of punishment phases, thus limiting the severity of punishment against possible defections from cooperative behaviors. Even though the incentive constraint has not defined, these restrictions on the lengths of punishment phases represented by the ICPs are clearly potential constraints for countries' supporting cooperative behaviors in the repeated game.

Therefore, it remains to be answered whether countries can support a cooperative equilibrium where protection levels are lower than the one-shot Nash equilibrium levels, with a punishment scheme satisfying the ICPs (thus, having restrictions on the lengths of punishment phases). Answering this question is the main focus of the following analysis.

3. Benchmark Case: Symmetric Countries with Almost Perfect Private Information

In this section, I investigate a case where countries are symmetric ($\Leftrightarrow$ u(p,q) = $u^*(p,q)$ for all p and q) and private information is almost perfect in the following sense:

$$\begin{aligned}&\mathrm{Var}(\theta_t|\phi_t) \to 0 \text{ and } \mathrm{Var}(\theta_t|\phi_t^*) \to 0\\ &\Rightarrow [\Pr(\tau^*) \to 0,\ \Pr^*(\tau) \to 0 \text{ for all } (\tau,\tau^*) \le (l,l^*)] \text{ and}\\ &\quad [\Pr(\tau^*) \to 1,\ \Pr^*(\tau) \to 1 \text{ for all } (\tau,\tau^*) > (l,l^*)]\end{aligned}$$

where $\mathrm{Var}(\ )$, $\Pr(\tau^*)$, and $\Pr^*(\tau)$ are defined as in Section 2. Therefore, as long as countries do not deviate from the cooperative equilibrium by setting higher protection levels than (l, l^*), the probability of any punishment phase to be invoked goes to zero.

With this almost perfect private information of other countries protection levels, I will show that symmetric countries can support a cooperative equilibrium (where protection levels are lower than the one-shot Nash levels) as a subgame perfect equilibrium of the repeated game with the trigger strategy described in the Section 2. In fact, symmetric countries with almost perfect private information can support any symmetric cooperative equilibrium ($l = l^*$) that can be sustained under perfect information with punishment schemes of triggering one-shot Nash tariff wars against defections.

Therefore, the result developed under this benchmark case implies that the "private nature" of the information of other countries' protection levels, which imposes the ICPs on the punishment scheme as discussed in Section 2, may not necessarily be a factor preventing countries to fully utilize such an information in support of freer trade. The robustness of this implication from the benchmark will be explored later in Section 4 and Section 5.

3.1. The Punishment Scheme Satisfying the ICPs

The focus of the analysis in this section is to characterize the level of cooperation sustainable through the punishment scheme defined in Section 2: $\bar{s}$ and $\bar{s}^*$ satisfying the ICPs. Therefore, I first characterize the punishment scheme satisfying the ICPs in this sub-section, and then based on the derived punishment scheme, the characterization of the cooperation is attempted in the following sub-section.

Since the ICPs are conditions to be satisfied in equilibrium and $\Pr(\tau^*) \to 0$, $\Pr^*(\tau) \to 0$ when $(\tau, \tau^*) = (l, l^*)$ under the assumption of almost perfect private information, I can rewrite ICPh in (7) into:

(8) <u>ICPh</u>:

$$(\beta - \beta^T) V_0(l) = q.$$

I will focus on the characterization of the home country's ICP, since I can easily get a similar expression for the foreign country due to the symmetric country assumption. In order to fully specify the ICPh in (8), I need to derive $V_0(l)$. Using the expected welfare functions in (5) together with the fact that $\Pr(l^*) \to 0$ and $\Pr^*(l) \to 0$, I can get the following expression for $V_0(l)$:

$$V_0(l) = u(l, l^*) / (1-\beta).$$

Note that the expected welfare from following the equilibrium path is equal to the welfare level of countries' playing the cooperative equilibrium $(\tau, \tau^*) = (l, l^*)$ all the time. This is because of the almost perfect private information which induces that the probability of a punishment phase to be initiated goes to zero, as long as countries do not deviate from the cooperative equilibrium where their protection levels are equal to (l, l^*).

Now, using $V_0(l) = u(l, l^*) / (1-\beta)$, I can rewrite the ICPh in (8) into:

$$(9) \quad \begin{aligned} &(\beta - \beta^T) u(l, l^*) / (1-\beta) = \\ &\beta u(h(l^*), l^*) + \beta^2 u(h, h^*) + \cdots + \beta^{T-2} u(h, h^*) + \beta^{T-1} \left[\lambda u(h, h^*) + (1-\lambda) u(l, l^*) \right] \end{aligned}$$

It is straight forward to show that for any (l, l^*) satisfying $u(h(l^*), l^*) - u(l, l^*) \leq \beta[u(l, l^*) - u(h, h^*)]/(1-\beta)$, there exist (T, λ) such that the above ICP of the home country can be satisfied. Note that $u(h(l^*), l^*) - u(l, l^*) \leq \beta[u(l, l^*) - u(h, h^*)]/(1-\beta)$ is the incentive constraint for the home country not to deviate from a cooperative equilibrium $(\tau, \tau^*) = (l, l^*)$ when countries employ a punishment strategy of triggering permanent reversion to a Nash tariff war against defections (under perfect information about other countries' protection levels). Therefore, as long as $(\tau, \tau^*) = (l, l^*)$ can be supported as a cooperative equilibrium under perfect information with a trigger strategy of employing permanent Nash tariff wars against defections, there exist a certain length of a punishment phase T-1 with proper value for λ such that the home country's ICP can be satisfied.

In addition, given the structure of $\bar{s}$ and $\bar{s}^*$ defined in Section 2, there exists a unique value for (T, λ) which satisfies the ICP for given levels of protection (l,l^*) to be supported in the cooperative equilibrium.[16] As mentioned earlier, a similar argument can be applied for the ICP of the foreign country due to the symmetric country assumption. Therefore, for given levels of protection (l,l^*) to be supported as a cooperative equilibrium, there exist uniquely defined $[T,T',\lambda,\lambda']$ which satisfy the ICP for the home and foreign country, as long as (l,l^*) are sustainable by a threat of triggering a permanent reversion to one-shot Nash tariff wars against defections.

The ICPs do not specify values for T^C and λ^C given (l,l^*). However, T^C and λ^C are irrelevant information for countries' unilateral decision on whether to deviate from the cooperative equilibrium or not, since the probability of a punishment scheme of using T^C and λ^C to be invoked is zero regardless of their unilateral decision on deviations. For any given levels of protection to be supported as a cooperative equilibrium, thus, the ICPs in (7) indeed "uniquely" define the punishment scheme against countries' unilateral defection considerations. This makes the characterization of the cooperative equilibria supportable with $\bar{s}$ and $\bar{s}^*$(satisfying the ICPs) to be a relatively easy task: I only need to specify the range of protection levels that can be supported with these uniquely defined punishment phases, $[T,T',\lambda,\lambda']$.

3.2. The Cooperative Equilibria Supportable with Private Information

In Section 2, we have postponed constructing the incentive constraints for not deviating from the cooperative equilibrium this section, since defining the optimal deviation path is a complicated problem given non-negligible levels of noises in countries' private information. However, with the assumption of almost perfect private

[16] It is true that λ can be any value on [0,1) for the case of $T\rightarrow\infty$. However, when $T\rightarrow\infty$, the punishment phase can be said to be uniquely defined regardless of the value for λ.

information (thus, errors in the private information become negligible), I can define the incentive constraints for supporting the cooperative behaviors.

A pair of protection levels (l,l^*) can be supported as a cooperative equilibrium (or as an agreement) only when the expected gain from keeping the agreement is greater than the expected gain from deviating from it for both the home and the foreign country. Thus, the incentive constraints for supporting the cooperative behaviors are:

IC for the home country (with a punishment scheme satisfying the ICP): ICh

(10) $$\begin{aligned} &u(l,l^*)+\beta u(l,l^*)+\cdots+\beta^{T'-2}u(l,l^*)+\beta^{T'-1}u(l,l^*) \ge u(h(l^*),l^*)+\beta u\left(h\left(h^*(l)\right),h^*(l)\right)+ \\ &\beta^2 u(h,h^*)+\cdots+\beta^{T'-2}u(h,h^*)+\beta^{T'-1}\left[\lambda' u(h,h^*)+(1-\lambda')u(l,l^*)\right], \end{aligned}$$

and similarly I can get:

IC for the foreign country (with a punishment scheme satisfying the ICP): ICf

(10') $$\begin{aligned} &u^*(l^*,l)+\beta u^*(l^*,l)+\cdots+\beta^{T-1}u^*(l^*,l) \ge u^*(h^*(l),l)+\beta u^*\left(h^*\left(h(l^*)\right),h(l^*)\right)+ \\ &\beta^2 u^*(h^*,h)+\cdots+\beta^{T-2}u^*(h^*,h)+\beta^{T-1}\left[\lambda u^*(h^*,h)+(1-\lambda)u^*(l^*,l)\right]. \end{aligned}$$

The left and the right sides of the above ICs respectively represent each country's gains from keeping and deviating from a cooperative equilibrium where countries are supposed to impose the cooperative protection levels (l,l^*).

Note that there is no probability terms in the above definitions of incentive constraints, reflecting that countries now assume to have almost perfect private information: any deviation from a cooperative equilibrium will be followed by a punishment phase with probability one and similarly, cooperative behaviors will continue the cooperative equilibrium with probability one. It is also important to note that the incentive constraints are defined for just one-time defection from the cooperative equilibrium: Since the repeated game has the same recursive structure for any period of the game where countries are supposed to impose their cooperative protection levels, it is enough to check the incentive constraints for one-time defection.

The home country's defection will be followed by a punishment phase with $(T'-1, \lambda')$, which is uniquely defined by the foreign country's ICP. Thus, the ICh compares the expected payoff of playing the cooperative equilibrium for T' periods with that of deviating from it, which will be followed by a punishment phase of $T'-1$ periods. When the home country tries to decide whether to deviate or not, the optimal initial deviation for each country is to impose its static optimal protection level given the other country's cooperative behavior, denoted by $h(l^*)$, since countries should expect that a deviation from the cooperative behavior will invoke a tariff war with probability one regardless of the initial defection level.

Then, the home country's optimal deviation strategy for the period right after its initial defection is to set its static optimal protection level given the foreign country will initiate a punishment phase with probability one. In the first period of the punishment phase the foreign country will imposes $h^*(l)$, since it expects the home country to impose the cooperative protection level (l) along the equilibrium path even when it receives private signals indicating the home country's defection. On the other hand, the home country will impose $h\left(h^*(l)\right)$ in the first period of the punishment phase following its deviation, since it expects the foreign country to impose $h^*(l)$ in the first period of the punishment phase. The optimal deviation strategy beyond the second period is irrelevant for the home country's initial decision to deviate, since it expect to play the one-shot Nash tariff war to the end of the punishment phase with probability one. Therefore, the ICh in (10) is indeed the incentive constraint for the home country not to deviate from the cooperative equilibrium, and a similar argument applies to the ICf defined above.

Now, in order to facilitate the characterization of the sustainable levels of cooperation, I focus on the symmetric cooperative equilibrium where $l = l^*$. This induces T to equal T', and λ to equal λ', which in turn makes the ICs in (10) and (10') equivalent to each other. Therefore, by focusing on the symmetric equilibrium, I can characterize the supportable level of cooperation only with the incentive constraint for the home country (or with the foreign country's). Using $T = T'$ and $\lambda = \lambda'$, I can rewrite the ICh in (10) as:

IC with l = l* in the cooperative equilibrium:

$$(11)\quad \begin{aligned} &u(l,l^*)+\beta u(l,l^*)+\cdots+\beta^{T-2}u(l,l^*)+\beta^{T-1}u(l,l^*)\geq u(h(l^*),l^*)+\beta u\left(h\left(h^*(l)\right),h^*(l)\right)\\ &+\beta^2 u(h,h^*)+\cdots+\beta^{T-2}u(h,h^*)+\beta^{T-1}\left[\lambda u(h,h^*)+(1-\lambda)u(l,l^*)\right]. \end{aligned}$$

As long as the expected gains from sustaining l $(=l^*)$ level of protection (the left side of the above inequality) is greater than the expected gains from deviating it by imposing its static optimal tariff, $h(l^*)\ (=h^*(l))$ and engaging in T-1 periods of tariff wars (the right side of the inequality), countries can support the symmetric cooperative equilibrium based on their private information of other countries protection levels. However, it is important to note that the length of the punishment periods, (T, λ) is uniquely defined by the ICPh in (9). Using the ICPh in (9), I can rewrite the above IC as:

$$\begin{aligned} &u(l,l^*)+\beta u(l,l^*)+\cdots+\beta^{T-1}u(l,l^*)\geq\\ &u(h(l^*),l^*)+\beta u(l,l^*)+\cdots+\beta^{T-1}u(l,l^*)-[[\beta u(h(l^*),l^*)-\beta u\left(h\left(h^*(l)\right),h^*(l)\right)] \end{aligned}$$

which in turn can be simplified into:

$$(12)\quad \beta[u(h(l^*),l^*)-u\left(h\left(h^*(l)\right),h^*(l)\right)]\geq u(h(l^*),l^*)-u(l,l^*)\ .$$

Now, I can easily establish the equivalence of the IC in (12) with the following inequality;

$$\beta\left\{[u(l,l^*)-u\left(h,h^*\right)]+\left[u(h,h^*)-u\left(h\left(h^*(l)\right),h^*(l)\right)\right]\right\}/(1-\beta)\geq u(h(l^*),l^*)-u(l,l^*)$$

This inequality is equivalent to $\beta[u(l,l^*)\text{-}u(h,h^*)]/(1\text{-}\beta)\geq u(h(l^*),l^*)\text{-}u(l,l^*)$, except for the term $\left[u(h,h^*)-u\left(h\left(h^*(l)\right),h^*(l)\right)\right]$ in the left side of the inequality. Since $\beta[u(l,l^*)\text{-}u(h,h^*)]/(1\text{-}\beta)\geq u(h(l^*),l^*)\text{-}u(l,l^*)$ is the incentive constraint for protection levels (l,l^*)

to be supported as a cooperative equilibrium by a punishment scheme of triggering permanent reversion to a Nash tariff war against defections, I can state the following proposition based on the above equivalency:

Proposition 1. Given $u(h,h^*) - u\left(h\left(h^*(l)\right), h^*(l)\right) \geq 0$ [17], symmetric countries with almost perfect private information can support any level of symmetric cooperation (l, l^*) that can be supported by a punishment strategy of invoking permanent reversion to the interior Nash tariff war against (possible) defections based on (almost) perfect public information.

This result challenges a potential conjecture about using private information to support freer trade between countries. The conjecture is that the private nature of the information may impose serious restrictions on the severity of punishment which countries can employ against defections, resulting in lower levels of cooperation than in cases where they could use public information as the triggering device for tariff wars against potential defections. If a Nash tariff war is the most severe way of punishing defections, the ICPs are not a binding constraint in sustaining a cooperative equilibrium since, even with the ICPs, countries can support any level of cooperation attainable through the most severe punishment scheme possible as a permanent reversion to Nash tariff wars.

The reason that ICPs are not binding constraints for symmetric countries in supporting a symmetric cooperative equilibrium can be explained by analyzing the relation between the ICPs and the ICs. Note that the ICPh in (9) ensures that the gains from a one-time defection for the home country is equal to the losses from T-2 periods of a tariff war following the defection. On the other hand, the ICh in (10) implies that when the home country actually defects, it will invoke a punishment phase with the length of

---

[17] As discussed in Bagwell and Staiger (1996), it can be shown that welfare for a country declines along its reaction curve as its trading partner imposes higher protection levels. Therefore, the sign of $[u(h,h^*) - u\left(h\left(h^*(l)\right), h^*(l)\right)]$ depends on the slope of countries' protection reaction curves: whether one country's static optimal protection level is an increasing or a decreasing function of the other's protection levels. If it is a decreasing function implying $h^*(l) > h^*$, $[u(h,h^*) - u\left(h\left(h^*(l)\right), h^*(l)\right)]$ will be positive since the home country can only suffer from raised protection levels by the foreign country.

T'-1 periods. As discussed earlier, $T = T'$ and $\lambda = \lambda'$ given the assumptions of symmetric countries and symmetric equilibrium. Therefore, the IC in (11) implies that the home country's defection will be punished by T-1 periods of a punishment phase, which is one period longer than the necessary periods to make the gains from defection equal to the losses from defection for the home country. Thus, the punishment phase satisfying the ICPh can be severe enough to prevent the home country from deviating from the cooperative equilibrium. Since I focus on the symmetric case, the same argument can be applied to the foreign country's defection.

However, note that the above argument ignores the slight difference between the punishment phase defined by the ICPh in (9) and that of the IC in (11). In the ICPh, the home country initiates a punishment phase by setting its explicit tariff rate higher than the cooperative level; from the next period, countries engage in a tariff war by setting their explicit tariff rates to be one-shot Nash tariff rates. On the other hand, in the IC, the home country's defection, of raising its protection level higher than the cooperative level through its non-tariff barriers, invokes a punishment phase. When the foreign country initiates a punishment phase based on its private signal, it assumes that the home country's protection level remains at the cooperative level, since it expects that country to follow the equilibrium path. Therefore, in the first period of the punishment phase of the IC in (11), the foreign country's protection level, $h^*(l)$ may not be its static optimal given that the home country's protection level is $h(h^*(l))$.

Compared with playing the one-shot Nash tariff war from the starting point of an invoked punishment, as specified in the ICPh, the home country may either suffer or benefit from the foreign country's sub-optimal behavior in the first period of the punishment phase of the IC in (11), depending on whether $u(h, h^*) - u(h(h^*(l)), h^*(l))$ is positive or negative, respectively. If it has a positive sign, then the IC in (11) implies that the home country's defection will be followed not only by one-shot Nash tariff war that is one period longer than the periods necessary to make the gains from defection equal to the losses from it for the home country, but also the payoff for the home country in the first period of the punishment would be lower than the one-shot Nash level. Therefore, $u(h, h^*) - u(h(h^*(l)), h^*(l)) \geq 0$ is indeed a sufficient condition for Proposition 1.

Proposition 1 has an implication for dispute settlement procedures of international trade agreements like the GATT or the NAFTA, which gather and disseminate (thus, *publicize*) information about possible defections from trade agreements. If the ICPs were binding constraints in supporting freer trade between countries, these dispute settlement procedures may play a role of relaxing the ICPs, making higher levels of cooperation feasible by strengthening punishments against defections. Proposition 1, however, implies that the ICPs are not binding constraints for symmetric countries with almost perfect private information to supporting a higher level of cooperation, thus the *private* nature of information does not necessitate the existence of dispute settlement procedures as a device to publicize the *private* information. Similar to previous papers on the workings of dispute settlement procedures, this benchmark result does not explain the role of dispute settlement mechanisms embodied in most international trade agreements.[18]

However, Proposition 1 focuses on a special case: symmetric countries with almost perfect private information using a specific punishment scheme (of triggering tariff wars against possible defections). Thus, the ICPs may still become binding constraints in more general cases: asymmetric country cases, or cases with large errors in observation. The private nature of the information may impose other kinds of constraints in supporting cooperation when countries employ different kinds of punishment schemes, like transferring future payoffs of the country suspected of high protection levels to the other country. Thus, through the rest of this paper, I investigate possible circumstances which may require a dispute settlement procedure as a device to publicize (imperfect) private information about possible defections from agreements in supporting a higher level of cooperation between countries.

4. Non-symmetric Countries with Almost Perfect Private Information

In this section, I relax the symmetric country assumption and investigate the effects of introducing this asymmetry on the use of private information in supporting freer

[18] For detailed discussion of papers on the role of dispute settlement mechanism in trade agreements, see

trade between countries. Section 4.1 provides a simple example where the result in Proposition 1 does not hold, with the example being designed to represent asymmetry in countries' abilities to change the terms of trade in their favor through protective import policies. A more general analysis on the asymmetric sized countries is provided in Section 4.2, using the model developed by Park (2000).

4.1. An example

To construct a simple example with asymmetry in countries involved in trade, I assume that the home [foreign] country can either choose a low protection level L [L^*] or a high protection level H [H^*], with the following payoffs for corresponding combinations of protection levels:

	L^*	H^*
L	(5,4)	(3.5)
H	(7,1)	(4,2)

where m [n] in (m,n) represents one-period payoff for the home [foreign] country. As illustrated in the above table, supporting (L, L^*) is a mutually beneficial option compared with the one-shot Nash equilibrium (H, H^*), thus countries are in a standard prisoner's dilemma situation in this tariff-setting game. Note that the home country is more able to change the terms of trade in its favor by imposing import protections than the foreign country: $u(H, L^*)$-$u(L, L^*)$=2 $>u^*(H^*,L)$- $u^*(L^*,L)$ = 1, and it gets fewer benefits from freer trade than the foreign country: $u(L, L^*)$-$u(H, H^*)$= 1 $< u^*(L^*,L)$- $u^*(H^*,H)$ = 2.[19]

The question is whether countries with payoff functions defined in the above table can support (L, L^*) as a cooperative equilibrium using a trigger strategy described in Section 2, with almost perfect private information of other countries' protection levels. The first step is to find out the trigger strategy satisfying the ICP for the home and foreign

---

Staiger (1995).

[19] This asymmetry in abilities of changing the terms of trade and in the gains from freer trade is typical for countries of asymmetric sizes. See Kennan and Riezman (1988) or Park (2000) for detailed discussions.

countries. Given the discount factor, β to be 9/10, a punishment phase is uniquely defined by the ICPs with [T=5, $T'=3$, λ =(290/792), λ' =(10/18)].

Then, I can easily show that the IC for the home country is violated under the trigger strategy satisfying the ICP, by showing:

$$u(L,L^*)+\beta u(L,L^*)+\beta^2 u(L,L^*) < u(H,L^*)+\beta u(H,H^*)+\beta^2\left[\lambda' u(H,H^*)+(1-\lambda')u(L,L^*)\right]$$

While countries cannot support the equilibrium with low protection levels (L,L^*) through a trigger strategy satisfying the ICPs, it is easy to show that countries can support the cooperative equilibrium by a trigger strategy employing permanent reversion to a Nash tariff war against possible defections from the cooperation with the same discount factor, β = 9/10. Thus, if countries can relax the constraints on the length of punishment phases by publicizing the information of protection levels through a dispute settlement procedure, thereby employing a more severe punishment, they will be better off by introducing such a measure. The above example, therefore, illustrates that the private nature of information may impose a serious constraint on the level of cooperation sustainable between countries of asymmetric size, opening up the possibility for mutually beneficial use of a dispute settlement procedure.

I can explain this result as follows. Since the gains from defection are relatively smaller for the foreign country than for the home country, the ICPs make periods of punishment invoked by the foreign country to be shorter than those by the home country, giving the foreign country a weaker punishment power against the home county's defections. On the other hand, the home country has a higher incentive to deviate, yielding its IC to be violated under a relatively weaker punishment by the foreign country.

As mentioned earlier, the above case is designed to exemplify asymmetry in countries' abilities in changing the terms of trade in their favor, which is typical for trade between countries of asymmetric size. Therefore, the natural extension from this example is to generalize the analysis into the case where countries are asymmetric in their sizes.

4.2. Countries of Asymmetric Size with Almost Perfect Private Information

In this section, based on the model developed by Park (2000), I analyze the case where countries of asymmetric size try to support freer trade with almost perfect private information of other countries' protection levels. In Park's model where a large country trades with a small country, only the large one is able to change the terms of trade in its favor by imposing import protections due to a large asymmetry in size of their economies. As a result, the large country may prefer playing the one-shot Nash equilibrium (where only the large country changes the terms of trade in its favor by imposing positive protection levels) to sustaining free trade with the small country. However, countries still have incentives to cooperate, since there exist gains from eliminating distortional effects of the large country's protection. A mutually beneficial arrangement is attainable if *distortional transfers (of income)* from the small to the large country, through the latter's positive tariffs, are replaced by *non-distortional transfers* through either direct transfers or reciprocal reduction in countries' protections.

In this section, I consider the case that the small country provides direct transfers, denoted by "s", to the large country as a price for the elimination of the large one's import protection. To sustain such an arrangement by a threat of invoking permanent reversion to one-shot Nash tariff wars against defections (under perfect information of other countries' protection levels), the following incentive constraints should be satisfied:

$$(IC^S) \qquad s \le \frac{\beta}{1-\beta}\left[(w^F - s) - w^N\right],$$

$$(IC^L) \qquad W^N - W^F \le \frac{\beta}{1-\beta}\left[(W^F + s) - W^N\right],$$

where IC^S and IC^L denote the incentive constraints for the small and the large country, respectively, and $(w^N, W^N)\,[(w^F, W^F)]$ represent the per-period levels of welfare for the small and the large countries, respectively, under the one-shot Nash tariff war [under free trade], with $\beta \in (0,1)$ representing the discount factor between periods. To sustain the free trade agreement, the gain from deviation for the small and the large countries (the left sides of IC^S and IC^L, respectively) should be less than the cost the country would bear after defecting from the agreement (the right sides of IC^S and IC^L, respectively). Note that $W^N > W^F$ and $w^N < w^F$, reflecting that only the large country imposes positive protections in the one-shot Nash equilibrium, thus having a higher level of welfare than under free trade.

If countries have high enough values for the discount factor, a free trade agreement can be supported by the trigger strategy of invoking permanent tariff wars against defections, with direct transfers from the small to the large country. Such transfers should satisfy the IC^S and IC^L at the same time, and the range of transfers that satisfy this requirement is given by:

(13) $$\frac{N}{\beta} \leq s \leq \beta \cdot F,$$

where $N \equiv W^N - W^F > 0$ and $F \equiv w^F - w^N > 0$. F is bigger than N, since there are distortional losses from the large country's positive protection levels in the one-shot Nash equilibrium, compared to free trade. However, it is important to note that the range of transfers defined in (13), with which a free trade agreement can be supported as a subgame perfect equilibrium of the repeated game, is derived based on the trigger strategy of employing a punishment scheme of invoking a permanent reversion to the one-shot Nash tariff war against defections.

When countries utilize private information of other country's defections in sustaining cooperation, the private nature of information will impose certain restrictions on the lengths of punishment phases to be invoked against defections, as discussed in Section 2. The focus of analysis is on the effects of these restrictions on the level of achievable cooperation between countries of asymmetric size. For this purpose, I analyze how the range of transfers, which with countries can support a free trade agreement, changes when they employ the trigger strategy defined in Section 2.

Similar to earlier analyses, the ICPs restrict the lengths of punishment phases, thus the ICs for the small and the large countries are given by:

$$(IC^S) \qquad s \le \beta(F-s) + \beta^2(F-s) + \cdots + \beta^{K-1}(F-s) + \beta^K \cdot \Lambda(F-s) \text{ with}$$
$$(ICP^L) \qquad \beta N = \beta^2(s-N) + \beta^3(s-N) + \cdots + \beta^{K-1}(s-N) + \beta^K \Lambda(s-N), \text{ and}$$
$$(IC^L) \qquad N \le \beta(s-N) + \beta^2(s-N) + \cdots + \beta^{k-1}(s-N) + \beta^k \lambda(F-s) \text{ with}$$
$$(ICP^S) \qquad \beta s = \beta^2(F-s) + \beta^3(F-s) + \cdots + \beta^{k-1}(F-s) + \beta^k \lambda(F-s),$$

where K[k] denotes the length of a punishment phase invoked by the large [small] country against the small [large] country's possible defections with $\Lambda\,[\,\lambda\,] \in [0,1)$ being the probability of playing the one-shot Nash equilibrium in the last period of the punishment phase. The length of the punishment phase in (IC^S) is restricted by (ICP^L), and the length of the punishment phase in (IC^L) is restricted by (ICP^S).

It is helpful to rewrite the above ICs and ICPs as follow:

$$(14) \quad \begin{array}{ll} (IC^S) & F/(F-s) \le \left\{1-\beta^K\left[1-\Lambda(1-\beta)\right]\right\}/(1-\beta) \text{ with} \\ (ICP^L) & N/(s-N) = \left\{\beta-\beta^{K-1}\left[1-\Lambda(1-\beta)\right]\right\}/(1-\beta), \text{ and} \\ (IC^L) & N/(s-N) \le \left\{\beta-\beta^k\left[1-\lambda(1-\beta)\right]\right\}/(1-\beta) \text{ with} \\ (ICP^S) & F/(F-s) = \left\{1-\beta^{k-1}\left[1-\lambda(1-\beta)\right]\right\}/(1-\beta). \end{array}$$

Note that all the expressions in the left sides of the above ICs and ICPs are (strictly) monotonic continuous functions of s. On the other hand, the expressions in the right sides of IC^S and ICP^L are (strictly) monotonically increasing functions in K, where the value of the expressions with $(K, \Lambda = 0)$ increases continuously to the value of the expressions with $(K+1, \Lambda = 0)$ as $\Lambda \to 1$ for all K. Similarly, the expressions in the right sides of IC^L and ICP^S are (strictly) monotonically increasing functions in k, where the value of the expressions with $(k, \lambda = 0)$ increases continuously to the value of the expressions with $(k+1, \lambda = 0)$ as $\lambda \to 1$ for all k. Therefore, for any value on the left sides of the above ICs and ICPs, there exists unique corresponding values for (K, Λ) and (k, λ) which satisfy the ICs and ICPs with equalities. This implies that for any given level of transfers, s, there exist unique punishment phases which satisfy the ICPs, defining (K, Λ) for the ICP^L and (k, λ) for the ICP^S.

To characterize the range of direct transfers with which countries can support a free trade agreement based on private information about other countries' defections, I introduce Figure 1. Figure 1 depicts ICPs and ICs (when they hold with equalities) in a space with s on the horizontal axis and (K, Λ) or (k, λ) on the vertical axis. Even though (K, Λ) and (k, λ) are not continuous variables, I can treat them as if they were by interpreting (K, Λ) to be equivalent to $K+\Lambda$ and (k, λ) to be equivalent to $k+\lambda$. This is because the expressions in the right sides of the IC^S and the ICP^L are (strictly) monotonically increasing functions in K, where the value of the expressions with $(K, \Lambda=0)$ increases continuously to the value of the expressions with $(K+1, \Lambda=0)$ as $\Lambda \rightarrow 1$ for all K, and similarly for (k, λ) of the IC^L and the ICP^S.

The length of punishment periods to be initiated by the large country, (K, Λ) on the ICP^L, goes to infinity as the amount of transfers s goes to N/β. Note that N/β is the minimum level of transfers with which a free trade agreement can be supported by a trigger strategy of invoking a permanent reversion to the one-shot Nash tariff war against defections, or equivalently, N/β is the level of transfers which makes the gains from one time defection for the large country equal to the losses from permanent reversion to the Nash tariff war. Since the ICP^L specifies the length of a punishment phase equating the gains from a one-time defection for the large country to be equal to the losses from the following Nash tariff wars, it is natural to have (K, Λ) on the ICP^L goes to infinity as s becomes closer to N/β. With a similar argument, I can explain why (k, λ) on the ICP^S goes to infinity as s goes to βF.

In Figure 1, the IC^L and the IC^S are located lower than the ICP^L and the ICP^S respectively by one period. This is because the left sides of ICs are equal to the corresponding left sides of ICPs in (14), and the right sides of ICs are equal to the corresponding right sides of ICPs in (14), except having K instead of k-1 for the IC^S and having k instead of K-1 for the IC^L. Using expressions in (14), it is easy to show that the value for (k, λ) on the ICP^S goes to $(k=2, \lambda=0)$ as $s \rightarrow 0$, and the value for (K, Λ) on the

ICP^L goes to (K=2, Λ =0) as s$\rightarrow\infty$. Similarly, the value for (K, Λ) on the IC^S goes to (K=1, Λ =0) as s$\rightarrow$0, and the value for (k, λ) on the IC^L goes to (k=1, λ =0) as s$\rightarrow\infty$.

Now, represent the intersection between $IC^S(K)$ with $ICP^L(K)$ by A and the corresponding level of transfers by $\bar{s}$. Similarly, denote the intersection between $IC^L(k)$ with $ICP^S(k)$ by B, and the corresponding level of transfers by $\underline{s}$. Since ICPs should be satisfied in any cooperative equilibrium, only points on ICPs can be supported as an equilibrium of this repeated game with private information. In addition, to eliminate unilateral incentives to deviate from the cooperation, ICs should also be satisfied in any cooperative equilibrium. These altogether imply that only points on the thick segments of the ICP^S and the ICP^L in Figure 1 can be supported as an equilibrium. Therefore, the overlapping portions between these two line segments on ICPs define a range of transfers, $[\underline{s}, \bar{s}]$, with which countries of asymmetric size can support a free trade agreement based on almost perfect private information of other countries protection levels.

As mentioned earlier, the main objective of this section is to analyze the effects of relying on private information to achieve potential cooperation between countries of asymmetric size. For this purpose, the following observation about $[\underline{s}, \bar{s}]$ in Figure 1 is useful. By analyzing the intersections between the ICs and the ICPs, depicted in Figure 1, it is easy to observe that $\bar{s}$ is greater than $\underline{s}$ as long as $\beta \cdot F$ is greater than N/β (and $\bar{s} = \underline{s}$ if $\beta \cdot F = N/\beta$). First, note that there exists an intersection point between the ICP^S and the ICP^L denoted by C, as long as $\beta \cdot F$ is greater than N/β. Now it is easy to understand that the point A (defining $\bar{s}$) should always be located to the right side of the point C, because A is an intersection between the ICP^L and the IC^S (which is located lower than ICP^S). With similar reasons, the point B (defining $\underline{s}$) should always be located to the left side of the point C, which justifies the observation that $\bar{s}$ is greater than $\underline{s}$, as long as $\beta \cdot F$ is greater than N/β.

Since N/β and $\beta \cdot F$ respectively denote the minimum and the maximum level of transfers with which a free trade agreement can be supported by the trigger strategy of invoking permanent tariff wars against defections from the agreement, the above observation about $[\underline{s},\bar{s}]$ in Figure 1 leads to the following proposition:

Proposition 2. If a small and a large country can support a free trade agreement with transfers from the small to the large country as a price for free trade using a punishment scheme of triggering permanent reversion to the one-shot Nash tariff war against defections (with perfect information), they can also support a free trade agreement with almost perfect private information about other countries' protection levels.

This is a version of Proposition 1 for countries of asymmetric size: If the Nash tariff war is the most severe way of punishing defections, the ICPs are not binding constraints in supporting a free trade agreement between a small and a large country. Therefore, Proposition 2 seems to contradict the example in Section 4.1, where the ICPs may become binding constraints in supporting a cooperative equilibrium between countries of asymmetric size.

However, the characterization of cooperative equilibria sustainable with private information in Figure 1, represented by $[\underline{s},\bar{s}]$, does not contradict the example in the previous section. It is a generalization of the insight developed in Section 4.1: Any cooperative equilibrium where one country gets most of the gains from the cooperation is not likely to be supported with imperfect private information. This point is illustrated in Figure 1 by the fact that $\left[\underline{s},\bar{s}\right]$, the range of transfers supportable with ICPs, is located inside $[N/\beta, \beta \cdot F]$, the range of transfer supportable without ICPs.

Therefore, the example considered in Section 4.1 corresponds to the case where countries try to support a free trade agreement with transfers, $s \in [N/\beta, \underline{s})$ in Figure 1, where more of gains from the free trade agreement goes to the small country: A free trade agreement with $s \in [N/\beta, \underline{s})$ cannot be supported with private information of other countries protection levels (or equivalently with the ICPs). Such an agreement, however, can be supported with a dispute settlement procedure which relaxes the ICPs by *publicizing* the private information of protection levels.

The above interpretation of the role of a dispute settlement procedure in international trade agreements is similar to the popular view that the GATT's dispute settlement procedure only serves the small countries' interests by raising their bargaining power (or the punishment power in the context of this paper) in trade disputes. Then, the analysis in this section could be used to rationalize this popular view of how the GATT works? The answer is "not necessarily."

Contrary to the example in Section 4.1, I can easily construct a case where countries try to support a free trade agreement with transfers, $s \in (\bar{s}, \beta \cdot F]$ in Figure 1, where most of gains from the free trade agreement goes to the large country. In that case, the same dispute settlement procedure can serve the large country's interests by *publicizing* the private information of protection levels, thus relaxing strengthening the large country's punishment power against the small country's defections. Therefore, the fact that $[\underline{s}, \bar{s}]$ is located inside $[N/\beta, \beta \cdot F]$ in Figure 1 does not necessarily mean the relaxation (or imposition) of the ICPs is a favorable action for the small country or for the large country.

One way that the ICPs (or the relaxation of the ICPs) may favor or disfavor one country at the expense of the other is through changing the range of supportable transfers favorable (or unfavorable) to one country. The following proposition, however, provide a negative result for this possibility.

Proposition 3. The middle point in the range of transfers $[N/\beta, \beta \cdot F]$ in Figure 1, with which countries (a small and a large) can support a free trade agreement by triggering permanent reversion to the one-shot Nash tariff war against defections (with perfect information), is still in the range of transfers $[\underline{s}, \bar{s}]$, with which they can support a free trade agreement with almost perfect private information of other countries' protection levels.

Proof. See Appendix A.

The range of transfers $\left[\underline{s},\bar{s}\right]$, with which countries can support a free trade agreement with the almost perfect private information is located around the middle of the range of transfers $[N/\beta, \beta \cdot F]$, with which they can support a free trade agreement by triggering permanent reversion to the one-shot Nash tariff war. Thus, Proposition 3, together with the preceding discussions, implies that there exists no strong ground for generally claiming that relying on private information instead of public information in supporting a free trade agreement between countries of asymmetric size may favor one country in expense of the other.

The implication of the analyses in this section can be summarized as follows. The private nature of the information of other countries' protection levels (which imposes certain restrictions on the punishment strategies through the ICPs) may not be a binding constraint if countries try to support freer trade where the gains are evenly distributed among countries, as long as the private information is accurate enough. However, when they try to support freer trade which generates uneven gains from it among countries, the private nature of information may become a binding constraint in supporting such cooperation even when the private information is really accurate: the ICPs disproportionately reduce the punishment power of the country who gains more from the freer trade than the other country.

It is often argued that the smaller countries gain more from freer (or free) trade than the larger countries do, since the favorable term of trade effects from freer trade will be greater for smaller countries than for the large one. Then, the private nature of the information that countries need to use against possible defections may impose a serious restriction on the smaller countries' punishment credibility against the larger countries' defections through non-tariff barriers, thus making freer trade hard to be supported between countries of asymmetric size. In this case, a dispute settlement procedure like that of GATT may restore the small countries' punishment credibility by relaxing the ICPs, which in turn helps countries to support freer trade.[20]

[20] The example in Section 4.1 is indeed a case where relaxing the ICPs through a dispute settlement procedure improves mutual interests of countries involved in trade. However, it is important to note that the possible actions in this example are very restricted, only allowing either a cooperative behavior or a non-cooperative behavior. This generates discontinuity in possible division of gains from freer trade among

Finally, it is important to note that the results in this section are based on specific assumptions regarding the accuracy of the private information of other countries' protection levels (presumed to be almost perfect) and the timing when the private information is revealed to countries (assumed to be such that the private information does not affect countries' incentives to change their protection levels). As discussed in the following sections, relaxation of these assumptions may lead to cases where a dispute settlement procedure of weakening the ICPs can enhance the mutual interests of countries involved in trade.

5. Asymmetry in Imperfect Private Information: An example

In this section, I construct a simple example where one country can control its import protection levels either through non-tariff barriers or through explicit tariff rates but the other country can control its protection levels only through explicit tariff rates. Thus, this example corresponds to a case where there exists a large asymmetry in transparency of countries' trade policies involved in trade. Then, I show that the constraint that the ICP imposes on the trigger strategy can easily become a binding constraint in supporting a cooperative equilibrium between these countries.

Similar to the example in Section 4.1, I assume that the home [foreign] country can either choose a low protection level L [L^*] or a high protection level H [H^*], with the following payoffs for corresponding combinations of protection levels:

	L^*	H^*
L	(1,1)	(-1.2)
H	(2,-1)	(0,0)

countries. Therefore, if countries can use some methods like direct transfers to redistribute gains more evenly as illustrated in Park (2000), they may relax the constraints imposed by the ICPs without relying on an institution like the GATT.

where m [n] in (m,n) represents one-period payoff for the home [foreign] country. Again, supporting (L, L^*) is a mutually beneficial option compared to the one-shot Nash equilibrium (H, H^*), yielding a standard prisoner's dilemma situation in the tariff-setting game. Note that the payoffs are symmetric across countries, eliminating any possible influence from asymmetry in the size of countries described in Section 4, on the possible equilibrium of the repeated game with imperfect private information.

To introduce asymmetry in countries' imperfect private information, I assume that only the foreign country can use non-tariff barriers in choosing its protection level. Thus, the home country's protection level is perfectly known to both countries, but the foreign country's protection level is perfectly known only to itself and the home country has only imperfect private information of the foreign protection level. Once again, the focus of analysis is to check whether countries can support the cooperative equilibrium (L, L^*) or not by the trigger strategy defined in Section 2: triggering a tariff war when countries' private signals of other countries' protection levels go below the critical levels.

Since only the foreign country has an access to non-tariff barriers, the incentive constraint for truth revelation of private information (ICP) only matters with the home country. In addition, note that $\Pr^*(L)$ =0; the probability of a punishment phase being invoked by the foreign country is equal to zero as long as the home country sustain its cooperative behavior by setting L level of protection, since the foreign country can perfectly observe the home country's protection level. Then, using $\Pr^*(L)$ =0, I can rewrite the ICPh in (7) into:

(15) $$\langle \text{ICPh} \rangle$$
$$\beta \cdot V_0(l) = q + \beta^T \cdot V_0(l)$$
$$\text{with } V_0(L) = \frac{u(L, L^*) + \Pr(L^*) \cdot q}{1 - \beta + \Pr(L^*)(\beta - \beta^T)}$$

where $V_0(L)$ is derived from (6). The ICPh in (15) can be further simplified into:

(15’) $u(L, L^*) = \frac{(1-\beta)\cdot q}{(\beta - \beta^T)}$.

Similar to the earlier analysis, the ICPh in (15’) uniquely defines (T, λ), thus the punishment scheme against the foreign country’s possible defections from the cooperative equilibrium. Given the payoff function defined above, this requires (T, λ) = (4, 10/81). From the second period of the repeated game, note that the home country’s defection from the cooperation is not distinguishable from its initiation of a punishment phase, since it will impose H level of explicit tariff in both cases. However, the ICPh in (15’) guarantees that the home country has no “strict” incentive to deviate from the cooperation by deviating to the high protection; the gain from deviation is equal to the gain from keeping the cooperation.

Given (T, λ) = (4, 10/81), therefore, whether countries can support (L, L^*) as the cooperative equilibrium or not depends on whether the foreign country has an incentive to defect from the cooperation or not. If the home country has almost perfect private information of the foreign country’s protection levels, I can use the result from Section 3: symmetric countries with almost perfect private information can support any symmetric cooperation (L, L^*) that can be sustained by a punishment strategy of using permanent reversion to the one-shot Nash tariff war (H, H^*) against defections under perfect information.

However, when the almost perfect information assumption is relaxed, I easily find a case where the ICPh becomes a binding constraint even with low levels of noises in the home country’s private information. For example, countries cannot support the cooperative equilibrium with $Pr^*(L)$ = 0.1, $Pr^*(H)$ =0.9, and β =0.9, since the foreign country has an incentive to deviate from it: $V_0^*(H^*) \approx 9.8594 > V_0^*(L^*) \approx 7.8294$, where $V_0^*(\tau^*)$ denote the foreign country’s expected discounted payoff at the initial period of the game from setting τ^* level of protection through non-tariff barriers when it is supposed to set the cooperative protection level, L^*.

If the home country can use a punishment longer than $(T, \lambda) = (4, 10/81)$, the above inequality can easily be reversed: $V_0^*(L^*) > V_0^*(H^*)$ with the same level of errors in the home country's private information and the same discount factor. Note that $V_0^*(H^*)$ represents the foreign countries' expected payoffs from a deviation strategy of imposing H^* level of protection all the time, thus may not be the highest payoff level it can achieve through any sorts of deviation strategies. Thus, $V_0^*(L^*) > V_0^*(H^*)$ does not necessarily mean that countries can support the cooperative equilibrium as the subgame perfect equilibrium against all possible deviation strategies.

However, if the home country's punishment power is strengthen by some sort of publicizing mechanism like the dispute settlement procedure of the GATT, which makes the repeated game with imperfect private information into that of imperfect public information, the usual recursive structure of the repeated game will be restored. Then, $V_0^*(L^*) > V_0^*(H^*)$ indeed becomes the sufficient condition for supporting (L, L^*) as a subgame perfect equilibrium of the repeated game with imperfect public information.

Therefore, the example illustrates a possibility that the ICP can become a binding constraint in supporting freer trade between countries when there exists a large asymmetry in transparency of their trade policies: the private nature of the information of other countries' protection levels through non-tariff barriers may weaken the credibility of strong punishment against the use of intensive non-tariff barriers. One way of escaping from the problem is to strengthen the punishment power against these non-tariff barriers by relying on a mechanism of publicizing the information about possible defections through non-tariff barriers. Given there exists large asymmetries in transparency of trade policies of countries involved in trade, a dispute settlement procedure like that of the GATT may play the role of strengthening the punishment power of the countries with highly transparent trade policies against other countries' extensive use of non-tariff barriers, thus enabling them to support mutually beneficial freer trade.

6. Conclusion

To address the enforcement issues regarding international cooperation for freer trade in the presence of non-tariff barriers, I analyzed the repeated game between two countries with imperfect private information of other countries' protection levels. Different from repeated games with perfect information or with imperfect public information, countries can misrepresent their private beliefs about other countries' protection levels. Due to this private nature of information, the trigger strategy based on the private information should be designed to provide right incentives for countries to truthfully reveal their private information. This restricts the length of tariff wars that countries can employ against possible defection from a cooperative equilibrium, represented by the ICPs in this paper. If the ICPs weaken the punishment power too much against defections, countries may not be able to support a cooperative equilibrium.

With almost perfect private information about others' protection, however, symmetric countries can support any level of symmetric cooperation sustainable under perfect information by threats of permanent reversion to Nash tariff wars against deviations (Proposition 1). This result implies that the private nature of the information that countries need to rely on for invoking punishments against possible defections may not be a binding constraint for symmetric countries to support freer trade, when the private information is very accurate.

However, this paper also identifies two cases where the ICPs (or equivalently, the private nature of information) become binding constraints for countries to support freer trade: the case with asymmetry in countries' incentives to sustain freer trade, and the other case with a large asymmetry in transparency of countries' trade policies. Then, in these cases, a dispute settlement procedure like that of the GATT (which publicizes the private information of countries' protection levels) can play a positive role in restoring cooperative behaviors by relaxing the ICPs.

Despite the extensive third party involvement (for example, the GATT) in solving international trade disputes over non-tariff barriers, the theoretical trade literature has largely ignored the role played by the third party in those disputes. In that regard, this analysis provides a new insight for the enforcement issue of international trade agreements: the private nature of the information that countries need to use in solving trade disputes over non-tariff barriers may necessitate a third party involvement like the GATT as a mean to strengthen the credibility of punishments against the use of non-tariff barriers.

One possible extension of this paper is to allow the private information to affect countries' incentives to deviate from the cooperative equilibrium. This will raise issues similar to the ones discussed in Bagwell and Staiger (1990): Countries would have high protection periods as a cooperative equilibrium, as well as low protection periods in the presence of shocks to the world economy. To provide proper incentives for countries not to deviate from the cooperation, high protection periods should be allowed depending on shocks to the world economy. But, the difference is that the shocks to the economies are no longer public information but private one. The private nature of the information about shocks to the economies may impose serious restrictions on the use of punishment schemes of invoking tariff wars against abusive uses of high protection periods.[21] Countries may not distinguish whether other countries invoke a tariff war for the purpose of punishment or they just invoke a tariff wars as the shocks to their economy give higher incentives to deviate from the low protection periods. This may necessitate a dispute settlement procedure (employing impartial third party panels who grant the right of using retaliatory measures against possible abuse of high protection periods) to screen the misrepresentation of private signals about shocks to the countries involved in trade.

[21] Athey and Bagwell (2001) and Athey et al. (forthcoming) consider similar issues in the context of collusive behaviors among firms. They analyze possible collusions in an infinitely-repeated Bertrand game, in which prices are perfectly observed and each firm receives a privately-observed i.i.d. cost shock in each period.

Appendix A

Proof for Proposition 3

To prove Proposition 3, I need to show that the middle point of $[\frac{N}{\beta}, \beta \cdot F]$, $\frac{N+\beta^2 \cdot F}{2\beta}$ is located within $[\underline{s}, \bar{s}]$. First, I show that $\frac{N+\beta^2 \cdot F}{2\beta} \geq \underline{s}$ and then $\frac{N+\beta^2 \cdot F}{2\beta} \leq \bar{s}$.

1. $\frac{N+\beta^2 \cdot F}{2\beta} \geq \underline{s}$

As illustrated in Figure 1, $\underline{s}$ is the intersection between the IC^L and the ICP^S. From (14):

$$(IC^L) \qquad \frac{N}{s-N} = \frac{\beta - \beta^k\left[1-\lambda(1-\beta)\right]}{(1-\beta)}, \text{ and}$$

$$(ICP^S) \qquad \frac{F}{F-s} = \frac{1-\beta^{k-1}\left[1-\lambda(1-\beta)\right]}{1-\beta}.$$

Note that the right side of the IC^L, $\frac{\beta - \beta^k\left[1-\lambda(1-\beta)\right]}{1-\beta}$ is equal the right side of the ICP^S, $\frac{1-\beta^{k-1}\left[1-\lambda(1-\beta)\right]}{1-\beta}$ when it is multiplied by β. Therefore, I can get $\underline{s}$ by finding the value for s such that $\frac{N}{s-N} = \frac{\beta \cdot F}{F-s}$. From this equality, I get

$$\underline{s} = \frac{N \cdot F \cdot (1+\beta)}{N + \beta \cdot F}.$$

Now, I can compare the above value for $\underline{s}$ with $\frac{N+\beta^2 \cdot F}{2\beta}$. Since

$$\frac{N+\beta^2\cdot F}{2\beta}-\underline{s}=\frac{(N-\beta\cdot F)(N-\beta^2\cdot F)}{2\cdot\beta\cdot(N+\beta\cdot F)},$$

whether $\frac{N+\beta^2\cdot F}{2\beta}\geq\underline{s}$ or $\frac{N+\beta^2\cdot F}{2\beta}<\underline{s}$, depends on the sign of $(N-\beta\cdot F)(N-\beta^2\cdot F)$.

Therefore, as long as $\beta\geq\sqrt{\frac{N}{F}}$, $\frac{N+\beta^2\cdot F}{2\beta}\geq\underline{s}$. Note that $\beta\geq\sqrt{\frac{N}{F}}$ is the condition for $[\frac{N}{\beta},\beta\cdot F]$ to be a non-empty set. Thus, I showed that the middle point of $[\frac{N}{\beta},\beta\cdot F]$ is larger than $\underline{s}$.

2. $\frac{N+\beta^2\cdot F}{2\beta}\leq\bar{s}$

To prove Proposition 3, now I need show the other inequality, $\frac{N+\beta^2\cdot F}{2\beta}\leq\bar{s}$ is also true. $\bar{s}$ is the intersection between the IC^S and the ICP^L as illustrated in Figure 1. From (14), I can rewrite:

(IC^S) $$\frac{s}{F-s}=\frac{\beta-\beta^K[1-\Lambda(1-\beta)]}{1-\beta},\text{ and}$$

(ICP^L) $$\frac{s}{s-N}=\frac{1-\beta^{K-1}[1-\Lambda(1-\beta)]}{1-\beta}.$$

Note that the right side of the IC^S, $\frac{\beta-\beta^K[1-\Lambda(1-\beta)]}{1-\beta}$ is equal the right side of the ICP^L, $\frac{1-\beta^{K-1}[1-\Lambda(1-\beta)]}{1-\beta}$ when it is multiplied by β. Therefore, I can get $\bar{s}$ by finding the value for s such that $\frac{s}{(F-s)}=\frac{\beta\cdot s}{(s-N)}$. From this equality, I get $\bar{s}=\frac{N+\beta\cdot F}{1+\beta}$.

Now, I can compare the above value for $\bar{s}$ with $\frac{N+\beta^2 \cdot F}{2\beta}$. Since

$$\bar{s} - \frac{N+\beta^2 \cdot F}{2\beta} = \frac{(1-\beta)(\beta^2 \cdot F - N)}{2 \cdot \beta \cdot (1+\beta)},$$

whether $\frac{N+\beta^2 \cdot F}{2\beta} \leq \bar{s}$ or $\frac{N+\beta^2 \cdot F}{2\beta} > \bar{s}$, depends on the sign of $(1-\beta)(\beta^2 \cdot F - N)$.

Therefore, as long as $\beta \geq \sqrt{\frac{N}{F}}$, $\frac{N+\beta^2 \cdot F}{2\beta} \leq \bar{s}$. Again note that $\beta \geq \sqrt{\frac{N}{F}}$ is the condition for $[\frac{N}{\beta}, \beta \cdot F]$ to be a non-empty set. Thus, I showed that the middle point of $[\frac{N}{\beta}, \beta \cdot F]$ is smaller than $\bar{s}$.

References

Abreu, D., 1988, On the Theory of Infinitely Repeated Game with Discounting, Econometrica 56, 383-396.

Abreu, D., D. Pearce and E. Stacchetti, 1986, Optimal Cartel Equilibria with Imperfect Monitoring, Journal of Economic Theory 39, 251-269.

Abreu, D., D. Pearce and E. Stacchetti, 1990, Toward a Theory of Discounted Repeated Game with Imperfect Monitoring, Econometrica 58, 1041-1064.

Athey, S. and Bagwell, K., 2001, Optimal Collusion with Private Information, Rand Journal of Economics 32:3, 428-465.

Athey, S. and K. Bagwell and C. Sanchirico, forthcoming, Collusion and Price Rigidity, Review of Economic Studies.

Bagwell, K. and Staiger, R., 1990, A Theory of Managed Trade, American Economic Review 80:4, 779-795.

Bagwell, K. and Staiger, R., 1996, Reciprocal Trade Liberalization, National Bureau of Economic Research Working Paper: 5488.

Bhaskar, V., 1994, Repeated Games with Almost Perfect Monitoring by Privately Observed Signals, mimeo.

Fudenberg, D. and D. Levine, 1991, An Approximate Folk Theorem with Imperfect Private Information, Journal of Economic Theory 54, 26-47.

Fudenberg, D., D. Levine and E. Maskin, 1994, The Folk Theorem with Imperfect Public Information, Econometrica 54, 26-47.

Green, E. and R. Porter, 1984, Noncooperative Collusion under Imperfect Price Information, Econometrica 52, 87-100.

Hudec R. E., 1993, Enforcing International Trade Law-The Evolution of Modern GATT Legal System, Butterworth Legal Publishers.

Johnson, H. G., 1954, Optimal Tariffs and Retaliation, Review of Economic Studies 21, 142-143.

Kandori, M., 1992, The Use of Information in Repeated Games with Imperfect Monitoring, Review of Economic Studies 59, 581-593.

Kandori, M. and H. Matsushima, 1998, Private Observation, Communication and Collusion, Econometrica 66, 627-652.

Kennan, John and Raymond Riezman, 1988, Do Big Countries Win Tariff Wars?, International Economic Review 29:1, 88-85.

Ludema, Rodney D., 2001, Optimal International Trade Agreements and Dispute Settlement Procedures, European Journal of Political Economy 17:2, 355-376.

Matsushima, H., 1990, On the Theory of Repeated Games with Private Information, Economics Letters 35, 257-261.

Park, J., 2000, International Trade Agreements Between Countries of Asymmetric Size, Journal of International Economics 50, 473-95.

Radner, R., 1986, Repeated Partnership Games with Imperfect Monitoring and no Discounting, Review of Economic Studies 53, 43-58.

Riezman, R., 1991, Dynamic Tariffs with Asymmetric Information, Journal of International Economics 30, 267-283.

Sekiguchi, T., 1997, Efficiency in Repeated Prisoner's Dilemma with Private Monitoring, Journal of Economic Theory 76, 345-361.

Staiger, R., 1995, International Rules and Institutions for Trade Policy, Handbook of International Economics, volume III .

Stigler, G., 1964, A Theory of Oligopoly, Journal of Political Economy 72, 44-61.

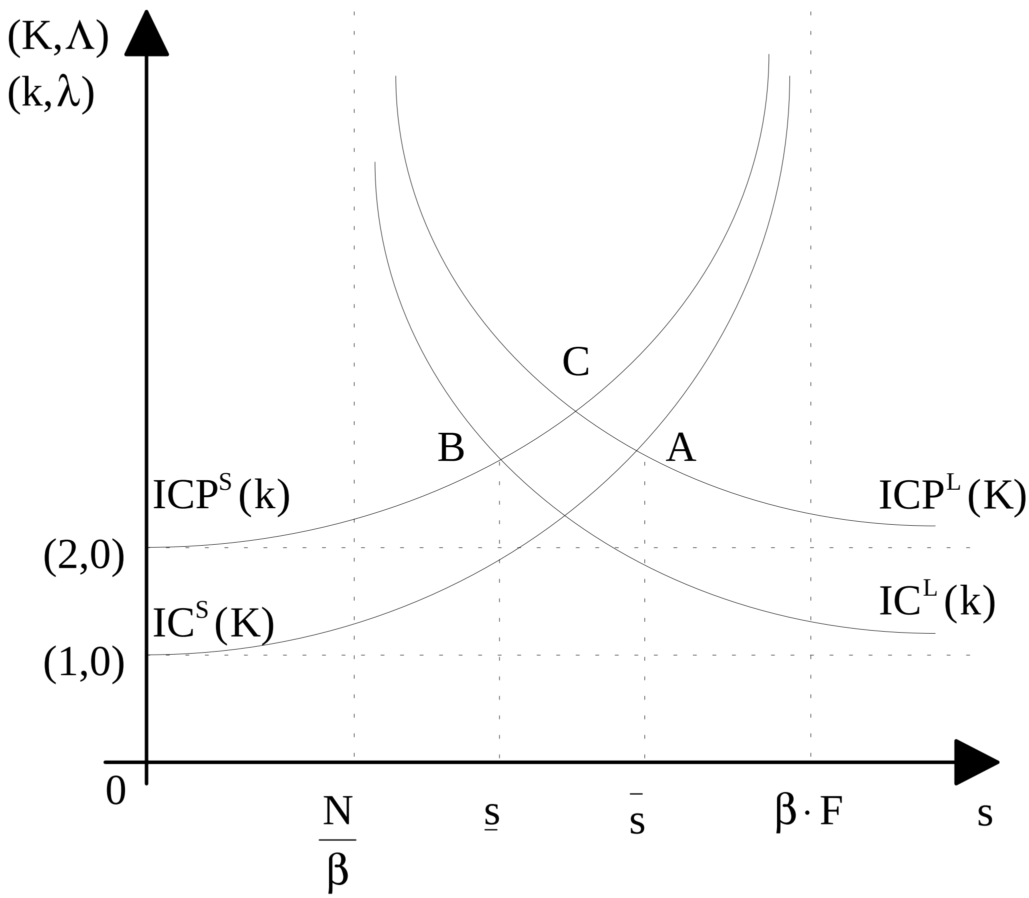
(K,Λ)
(k,λ)
C
B
A
ICP^S(k)
ICP^L(K)
(2,0)
IC^S(K)
IC^L(k)
(1,0)
0
$\frac{N}{\beta}$
$\underline{s}$
$\bar{s}$
$\beta \cdot F$
s

Figure 1