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Authors: Hideo Konishi, Minoru Nakada, Akihisa Shibata

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Hideo Konishi† Minoru Nakada‡ Akihisa Shibata§

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Abstract

In this paper, we investigate the effects of a free trade agreement (FTA) with environmental standards between Northern and Southern countries, with explicit considerations for transferring clean technology and enforcing reduced emissions. Southern producers benefit greatly by having access to a Northern market without barriers, while they are reluctant to use new high-cost, clean technology provided by the North. Thus, environmentally conscious Northern countries should design an FTA where Southern countries provide sufficient benefits for the membership while imposing tighter enforcement requirements. Since including too many Southern countries dilutes the benefits of being a member of the FTA, it is in the best interest of the North to limit the number of Southern memberships while requiring strict enforcement of emissions reduction. This may result in unequal treatment among the Southern countries. We provide a quantitative evaluation of FTA policies by using a numerical example.

Keywords: Free trade agreements; Environmental standards.
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††Hideo Konishi: Department of Economics, Boston College, USA. Email: hideo.konishi@bc.edu

‡Minoru Nakada: Graduate School of Environmental Studies, Nagoya University, Japan. Email: mnakada@cc.nagoya-u.ac.jp

§Akihisa Shibata: Institute of Economic Research, Kyoto University, Japan. Email: shibata@kier.kyoto-u.ac.jp

1 Introduction

In the current era of rapid international integration of goods and financial markets, the environment of a country is significantly affected by other countries' economic activities. While various arguments have been raised about the relationship between free trade and the environment, one of the main issues is whether international trade between developed and developing countries affects positively or negatively the environment. There are a number of discussions on the above question among researchers both from theoretical and empirical points of view. Some researchers argue that trade liberalization may cause the relocation of pollution intensive firms from high-income countries with stringent pollution regulation (Northern countries) to low-income countries with weaker regulation (Southern countries). Although pollution in the North may be reduced, free trade is likely to have negative impacts on global pollution as well as pollution in the South, because dirtier firms are located in economies with laxer environmental regulation, this is called the Pollution Haven Hypothesis (Taylor, 2005). As Copeland and Taylor (1994) suggested, the role of income inequality between countries is important in determining the impact of trade on the environment; free trade can raise pollution when the degree of income inequality between countries is relatively high. Concerning the present income disparities between Northern and Southern countries, we could assume that trade liberalization affects the environment negatively if differences in incomes and the degree of environmental regulation among countries are significant.

However, empirical evidence demonstrates that this prediction may not necessarily be true. While Managi et al. (2009) displayed that trade has negative effects on the environment in non-OECD countries, Antweiler et al. (2001) showed that freer trade is in fact good for the environment. Cole (2004) demonstrated that the North American Free Trade Agreement (NAFTA) caused no pollution haven effect in Mexico. Gutierrez and Teshima (2018) pointed out the importance of technology upgrades induced by NAFTA for pollution reduction in Mexico. Such evidence highlights the importance of giving developing countries access to markets as their motivation to adopt cleaner technologies. This diffusion of such technologies via trade might be essential for developing countries to reduce pollution (Taylor 2004).

What would happen if a potential trade partner has a government that lacks the capacity for policy enforcement? In reality, there are some preferential trade agreements between developed and developing countries that contain provisions of environmental conservation. A good example is the European Union. The EU has enlarged member states ever since its establishment. According to EU (2014), 10 states, including Baltic countries, joined the Union in 2004, and Romania and Bulgaria became new members in 2007. These new member states are not high-income countries compared to the original members such as France and Germany. During such enlargement processes, the EU examines whether prospective member states can apply EU legislation, regarding environmental conservation. For that purpose, the European Commission also provided multilateral technical assistance to Baltic counties such as Estonia, Latvia, and Lithuania before the accession of those countries as member states (WB 2007). The enlargement process is still in progress, and now covers Turkey, Croatia and the former Yugoslav Republic of Macedonia. From an environmental point of view, participation of these candidates might improve the environment if they could perfectly apply stringent EU environmental regulations. However, the World Bank suggests that, because the governmental effectiveness of those Balkan counties ranks below the average of existing EU member states, their enforcement level should be improved. As a result, there may exist a potential tradeoff between an increase in the number of member states and the level of enforcement of new member states, and it may be costly to enlarge membership for Southern countries while keeping the same enforcement level.[1]

In the case of NAFTA, the North American Agreement on Environmental Cooperation (NAAEC) was agreed among three countries: Canada, Mexico, and the United States. Although it allows each country to establish its own levels of domestic environmental protection, the agreement requires member countries to conserve the environment and moreover, each country is recommended to provide for high levels of environmental protection (CEC 1993). The US had several programs to support Mexico in ensuring compliance with environmental laws and increasing enforcement capacity along their borders (EPA 1991). In NAFTA case, Mexico is the only developing country. However, in the EU case, the costs for such an assistance program could be substantial. Therefore, it is essential to find an optimal number of participants and an optimal enforcement level and to examine whether financial support for member states is effective.

In this paper, we develop a model of a free trade agreement (FTA) with environmental standards.[2] There are one North and multiple Southern countries; Northern country can

[1] In order to improve the ability to enforce regulation, the European Commission began to support a capacity building program for improving environmental enforcement (WB 2007).

[2] In the literature on international agreements on climate change, many researchers study self-enforcing environmental agreements (SIEAs) by using cooperative game theory such as Barrett (1993), Carraro and Siniscalco (1993), Eichner and Pethig (2013a, 2013b and 2015), and Kuhn et al. (2015).

sign an FTA with any number of Southern countries. We consider costly clean and cheap dirty technologies to produce a manufacturing good to be traded; the Northern country has a clean technology and the Southern countries have only a dirty technology without free trade agreements with the North. If a Southern country establishes the agreement with the North, the Southern country can adopt the clean technology. However, the Southern country has an incentive to cheat and use the cheap dirty technology. In order for a Southern country to monitor whether its firms are using the clean technology, it must spend an enforcement cost, which can differ among each country. In order to ensure that Southern countries use the clean technology, the Northern country might need to provide them monetary support to allow them to join the FTA with a certain enforcement level. That is, there are tradeoffs between the number of Southern participants and the enforcement level that the FTA imposes on the members.

The main incentive method used by Northern countries to encourage Southern countries to use the high-cost clean technology with strict enforcement is to limit the number of Southern participants. If the number of Southern countries in the FTA is small, these countries get great benefits by being included by the FTA (i.e., by having exclusive accesses to a lucrative Northern market), so they are willing to enforce the high-cost clean technology while demanding less transfer. Obviously, the Northern country's consumers may want more Southern competitors for a lower price, but by including more Southern countries, the enforcement level goes down and they demand more transfers for participation in the FTA. Note that this arrangement necessarily involves an inequality issue among Southern countries. The ones in the FTA get access to the Northern market and prosper. In contrast, the ones excluded from the FTA lose business with the Northern country, becoming even poorer than before. An FTA with environmental standards may increase inequality among Southern countries.

We first show that for any given level of enforcement and monetary support, there is a stable free trade agreement in the sense that (i) no member country wants to quit the FTA unilaterally, and (ii) no outsider wants to participate in the FTA unilaterally (Proposition 1). This stability notion was first introduced by d'Aspremont et al. (1983) for the analysis of cartels and is widely used by environmental economists (see Barrett 1994). Then, using linear technologies and demand, we show that if a Northern country is setting the rule by maximizing its social welfare, then the enforcement level of the clean technology usage (what fraction of production uses the clean technology) goes down as the number of Southern participants increases (Proposition 2).

With Proposition 2, it is easy to see that there is a tradeoff between having more Southern countries in the FTA and the level of enforcement, but there are other tradeoffs as well. With more Southern memberships, a Northern country's consumer surplus increases, while its domestic firm's profit and its tariff revenue decrease. We also do not know how the total amount of emissions would be affected by an increase in the number of Southern countries in the FTA since the enforcement level for the FTA members goes down while the number of Southern countries goes up. Moreover, as the Southern membership goes up, the total transfers to them become more and more costly for the Northern countries. Since all of these factors are important and it is hard to get qualitative results, we will present an example with reasonable parameter values and observe the optimal FTA policy for the Northern country and its environmental implications.

In the numerical example, we confirm that these considerations play important roles in evaluating the FTA policies. Limiting Southern memberships is desirable for Northern countries, but it results in sizable inequality between the FTA members and nonmembers among Southern countries. Comparative static analyses of the numerical example demonstrate that, if the number of member states is kept constant, an increase in emissions from Southern countries raises the aggregate emissions. However, it also shows that, once the number of member states is endogenized, its overall effect on the aggregate emissions is negative, due to the subsequent increase in the number of Southern participants, which adopt clean technologies.

2 The Model

2.1 The basic structure of the model

There is one Northern country and m Southern countries in the world, and all Southern countries are identical ex ante. The set of Southern countries is denoted by $S = \{1, ..., m\}$. The Northern country (denoted by 0) has an inverse demand function for an industrial good $P(\bar{Q})$, while Southern countries have identical inverse demand functions for the industrial good $p(q_j)$, where $\bar{Q}$ and q_j are aggregated quantities in the Northern and Southern country j's markets, respectively. We assume that P and p are twice continuously differentiable. Northern and Southern countries' wage rates (opportunity cost of labor) are exogenously fixed at w_N and w_S, respectively ($w_N > w_S > 0$).[3] There are two technologies that produce industrial goods, clean and dirty technologies. In order to produce one unit of an industrial good, the clean and dirty technologies (C and D, respectively) require α_C and α_D units of labor, respectively ($\alpha_C > \alpha_D > 0$). That is, the clean technology requires more labor input to produce one unit of output than the dirty technology. Initially, the Northern country has the clean technology C, while all Southern countries have the same dirty technology D. The amount of emissions by producing one unit of product with the clean and dirty technologies are denoted by e_C and e_D, respectively, with $e_D > e_C \geq 0$.

The Northern country applies a common specific tariff rate $\tau > 0$ on imports from Southern countries. Unless Southern country j has a free trade agreement with the Northern country, tariff rate τ applies. We fix τ throughout this paper (τ is not a policy variable). This is because the WTO prohibits increasing tariffs when countries form an FTA.[4] A free trade agreement does not allow a country to export goods to a country indirectly via a third country. Each country $j \in \{0\} \cup S$ has a single firm (only Northern countries consume industrial good). Country j's export quantity to Northern country 0 is denoted by Q_j, and country 0's domestic supply is denoted by Q_0. Thus, the total supply in country 0 is $\bar{Q} = \sum_{j \in S} Q_j + Q_0$.

We will also assume that Southern countries do not import industrial goods. This assumption is imposed for simplicity of the analysis, and gives the worst incentive for Southern countries to participate in the FTA.

2.2 Free trade agreement, environmental standard, and law enforcement

The WTO allows for countries to form FTAs, but requires that countries in an FTA abolish tariff rates on imports from all member countries mutually (although in our model Southern countries do not import industrial goods). Since our interest is in how international trade

[3]This assumption implies that w_N units of the numeraire good can be produced from one unit of labor in the Northern country, while w_S units of the numeraire good can be produced from one unit of labor in Southern countries. Country 0 produces one unit of an industrial good by using α_C units of labor, which means that it gives up $w_N \alpha_C$ units of numeraire (opportunity cost) by producing one unit of the industrial good.

[4]One of the key principles of the WTO is nondiscrimination. (Obviously, FTA itself is a discrimination, but GATT's Article 24 allows for FTAs and custom unions as long as they do not provide negative externalities to outsiders.) Increasing τ appears to discriminate outsiders from FTA members, even though it is motivated by a Northern country's intention to encourage Southern countries to join an FTA.

affects the total emissions in the world, we assume that for a Southern country to form an FTA with Northern country 0, the Southern country must accept an environmental standard set by the North with a required enforcement level. We denote FTA partners with Northern country 0 by set $A \subseteq S$.

This means that when Northern country 0 and country $j \in S$ form an FTA, country j must adopt clean technology C that requires α_C units of labor, and enforce the usage of the clean technology at least to some extent by spending a fixed cost to establish law enforcement. This is because the dirty technology has a lower marginal cost than the clean technology: $\alpha_D < \alpha_C$. Without an enforcement mechanism, producers are tempted to use the dirty technology, so law enforcement needs to randomly audit to check if the clean technology is being used. We will denote the level of enforcement of the clean technology implicitly by $\xi_j \in [0, 1]$: country j's firm produces only fraction ξ_j of its output with the clean technology and the rest of its output $(1 - \xi_j)$ is produced with the dirty technology to save some money. Enforcing the usage of the clean technology can be costly, since it requires infrastructure such as an audit system and well-disciplined police, which in turn requires a fixed cost. Let $F_j(\xi)$ be country j's cost of introducing the clean technology together with the cost to establish law enforcement that achieve enforcement level $\xi \in [0, 1]$. We assume $F_j(\xi) = F + f_j(\xi)$ with $F \geq 0$, $f_j(0) = 0$, $f_j'(\cdot) > 0$, and $f_j''(\cdot) > 0$. We assume that F_js are ordered by efficiency of enforcement technology: i.e., *for any* $\xi \in [0, 1]$, $f_1(\xi) \leq f_2(\xi) \leq ... \leq f_m(\xi)$ *and* $f_1'(\xi) \leq f_2'(\xi) \leq ... \leq f_m'(\xi)$ *holds.*

Let the total amount of pollutive emissions in the world be described by

$$E = e_C Q_0 + \sum_{j \in S} \left(\xi_j e_C + (1 - \xi_j) e_D\right) (Q_j + q_j),$$

where $\xi_j e_C + (1 - \xi_j) e_D$ is country j's emission rate for $j \in A$, and $Q \equiv (Q_0, ..., Q_m)$ and $q \equiv (q_1, ..., q_m)$ denote supply vectors in the Northern and Southern countries, respectively. Northern and Southern countries receive negative externalities from pollutive emissions in an additive manner (global pollutive emissions) by $d_N E$ and $d_S E$, respectively, where $0 \leq d_S < d_N$.

3 Analysis

3.1 Northern market equilibrium allocation

We will analyze Northern country 0's market equilibrium. Firms in different countries have different effective marginal costs. The firm in country 0 has marginal cost $c_0 = w_N \alpha_C$, the one in Southern country $j \in A$ has marginal cost $c_j = w_S \alpha_C$ if $j \in A$, and the one in country $j \in S \backslash A$ has marginal cost $c_j = w_S \alpha_D + \tau$ if $j \in S \backslash A$. When there are m countries that supply the product to country i, and they have heterogeneous costs $(c_0, c_1 ..., c_m)$, the standard Cournot equilibrium solution can be obtained in the following manner: Country j's best response to q^i_{-j} is a solution of

$$\max_{Q_j} P\left(\sum_{i=0}^{m} Q_i\right) Q_j - c_j Q_j,$$

i.e., the first order condition

$$P\left(\sum_{i=0}^{m} Q_i\right) - c_j + P'\left(\sum_{i=0}^{m} Q_i\right) Q_j = 0.$$

Summing them up, we have

$$(m+1) P\left(\bar{Q}\right) - \sum_{i=0}^{m} c_i + P'\left(\bar{Q}\right) \bar{Q} = 0. \tag{1}$$

This equation determines $\bar{Q} = \sum_{j=0}^{m} Q_j$ and $P(\bar{Q})$ uniquely as long as the **strategic substitute condition** ($P'(\bar{Q}) + P''(\bar{Q}) Q_j \leq 0$ for all $\bar{Q}$ and $Q_j < \bar{Q}$) is satisfied. The equilibrium allocation is described only by $\bar{Q}$: for all $j = 0, ..., m$

$$Q_j(\bar{Q}) = \frac{P(\bar{Q}) - c_j}{-P'(\bar{Q})}$$

and

$$\Pi_j(\bar{Q}) = \frac{(P(\bar{Q}) - c_j)^2}{-P'(\bar{Q})}, \tag{2}$$

as long as $P(\bar{Q}) \geq c_j$ is satisfied (otherwise, $Q_j = 0$ holds and firm j becomes an inactive firm: i.e., the number of firms in the market shrinks, but all nice properties still hold even after some firms become inactive). We can show that under the strategic substitute condition, we have

$$\frac{d\bar{Q}}{d\left(\sum_{i=0}^{m} c_i\right)} = (m+2)\, P'\left(\bar{Q}\right) + P''\left(\bar{Q}\right)\bar{Q} < 0 \tag{3}$$

and $\bar{Q}$ is uniquely determined by $\sum_{i=0}^{m} c_i$ (monotonic decreasing function). This in turn determines firm j's profit, which is a decreasing function of Q:

$$\begin{aligned}\frac{\partial \Pi_j}{\partial \bar{Q}} &= \frac{2P'\left(P-c_j\right)\left(-P'\right) - \left(P-c_j\right)^2\left(-P''\right)}{\left(-P'\right)^2} \\ &= \frac{\left(P-c_j\right)}{\left(-P'\right)}\left[2P' + P'' q_j\right] < 0.\end{aligned}$$

Thus, keeping c_j constant, if $\sum_{i=0}^{m} c_i$ decreases, Π_j goes down.

3.2 Southern market equilibrium allocation

In contrast, we greatly simplify each Southern country's market equilibrium. Let country j's domestic inverse demand function be $p(q_j)$.

If country j is not participating in an FTA with Northern country 0, then the firm in country j uses the dirty technology D:

$$\pi_j(q_j) = p(q_j)q_j - w_S\alpha_D q_j. \tag{4}$$

Clearly, firm j in a nonmember country chooses a monopoly output level given marginal cost $w_S\alpha_D$: $p - w_S\alpha_D + p' q_D = 0$. Let us denote the Southern countries' monopoly output and profit with the dirty technology by q_D and $\pi_D = \frac{(p(q_D)-w_S\alpha_D)^2}{-P'(q_D)}$.

There are several different possible scenarios for the marginal cost of production of a Southern FTA member country with enforcement level ξ. One reasonable assumption is that marginal cost of production in deciding how much to produce is based on the clean technology's marginal cost $c_j = \alpha_C w_S$, even though average cost is $\left(\xi_j\alpha_C + (1-\xi_j)\alpha_D\right) w_S$. This case is justified if the firm itself has a good intention to use the clean technology, while workers do shirk by producing fraction $1-\xi_j$ of its output to earn the difference in marginal costs. *We will assume that country j's firm operates using its marginal cost $c_j = \alpha_C w_S$ throughout the paper.*[5]

[5]Practically, if a firm in a Southern country determines its output with a marginal cost lower than $w_S\alpha_C$, it becomes obvious that its firm is using the dirty technology. Thus, our assumption makes sense. However, it is also easy to assume that the marginal cost is the same as the average cost $c_j = \left(\xi_j\alpha_C + (1-\xi_j)\alpha_D\right) w_S$, which can be justified if the firm is choosing its output level based on knowledge of the usage of dirty technology (so

Under this assumption, an FTA member country's monopoly output q_C is determined by $p - w_S\alpha_C + p'q_j = 0$. Its profit is denoted by $\pi_C = \frac{(p(q_C) - w_S\alpha_C)^2}{-p'(q_C)}$. Since $\alpha_D < \alpha_C$, $q_C < q_D$ and $\pi_C < \pi_D$ hold. The firm gets the exporting and domestic profits with the clean technology, and cheating workers get $(1-\xi_j)(\alpha_C - \alpha_D) w_S (Q_j + q_j)$.

3.3 Global equilibrium allocation with an FTA

Suppose that k Southern countries are in the FTA ($|A| = k$) and agree to use the clean technology: i.e., countries in $A \cup \{0\}$ adopt the technology. Since Southern countries' marginal costs depend only on the (official) technologies they use, the equilibrium output allocation vector is solely determined by A (or k), too. Agreed enforcement level ξ affects social welfare through the worldwide emission of pollutive substances E and Southern member countries' policy enforcement only.

Let $\bar{Q}(k)$ be the solution of equation (1) for $c_0 = w_N\alpha_C$, $c_j = w_S\alpha_C$ for all $j \in A$, and $c_j = w_S\alpha_D$ for all $j \notin A$. The Northern country's consumer surplus is described by $CS(k) = \int_0^{\bar{Q}(k)} \left(P(\tilde{Q}) - P(\bar{Q}(k))\right) d\tilde{Q}$. Let $Q(k) \equiv (Q_0(k), Q_1(k), ..., Q_m(k))$ and $\Pi(k) \equiv (\Pi_0(k), \Pi_1(k), ..., \Pi_m(k))$ be such that $Q_j(k) \equiv Q_j(\bar{Q}(k))$ and $\Pi_j(k) \equiv \Pi_j(\bar{Q}(k))$ for the above $c = (c_0, c_1, ..., c_m)$. Countries' supply and profit vectors in the Northern market are dependent on their technologies: $Q_j(k) = Q_C(k)$ and $\Pi_j(k) = \Pi_C(k)$ for $j \in A$, and $Q_j(k) = Q_D(k)$ and $\Pi_j(k) = \Pi_D(k)$ for $j \notin A$. Southern countries' domestic supply vector is simply determined as $q_j = q_C$ if $j \in A$, and $q_j = q_D$ otherwise.

The Northern country sets a clean-technology enforcement level $\xi \in [0,1]$ and a sign-up subsidy $\sigma \geq 0$ for its FTA member (Southern) countries, and the Northern country agrees to form a free trade agreement with Southern country j as long as country j is willing to adopt the clean technology by spending enforcement cost $F_j(\xi) \geq 0$ (open membership, or non-discrimination). The worldwide emission of pollutive substance under this free trade agreement is described by

$$\begin{aligned} E(k,\xi) &= e_C Q_0(k) + \sum_{j \in A} (\xi e_C + (1-\xi)e_D)(Q_j(k) + q_C) + \sum_{j \in S \setminus A} e_D(Q_j(k) + q_D) \\ &= e_C Q_0 + k(\xi e_C + (1-\xi)e_D)(Q_C + q_C) + (m-k)e_D(Q_D + q_D). \end{aligned}$$

firm's output decision is affected by ξ). In the former case, $\frac{dc_j}{d\xi} = 0$, while in the latter case, $\frac{dc_j}{d\xi} > 0$ holds. Despite the difference in the underlying assumption, the quantitative results are the same.

The Northern country's social welfare can be written as

$$SW(k,\xi,\sigma) = CS(k) + \Pi_0(k) - k\sigma - d_N E(k,\xi).$$

Southern countries' consumer surplus is described by $cs_j = cs_D \equiv \int_0^{q_D} (p(q) - p(q_D))\, dq$ if $j \notin A$, and $cs_j = cs_C \equiv \int_0^{q_C} (p(q) - p(q_C))\, dq$ if $j \in A$. Southern countries' social welfare can be written as

$$sw^{OUT}(k,\xi) = sw(k,\xi) \equiv cs_D + \Pi_D(k) + \pi_D - d_S E(k,\xi) \tag{5}$$

if $j \notin A$, and

$$\begin{aligned} sw^{IN}(k,\xi) = sw(k,\xi) \equiv\ & cs_C + \Pi_C(k) + \pi_C + \sigma - F(\xi) \\ & + (1-\xi)\,(\alpha_C - \alpha_D)\, w_S\,(Q_C + q_C) - d_S E(k,\xi) \end{aligned} \tag{6}$$

if $j \in A$.

3.4 Participation decision in an FTA

Here, we consider an FTA between Northern country 0 and some Southern countries. We analyze the set of equilibrium participants in the free trade agreements with Northern country 0. Let $A \subset S$ be the set of Southern countries that participate in free trade agreements, and let its cardinality be $a = |A|$. Note that all countries j in A have marginal costs $c_j = w_S\alpha_C$ and countries j in $S \backslash A$ have marginal costs $c_j = w_S\alpha_D + \tau$. The equilibrium set A of the Southern FTA member countries k is described by the following two inequalities:

$$sw^{IN}(k,\xi) - F - f_j(\xi) + \sigma \geq sw^{OUT}(k-1,\xi) \text{ for all } j \in A \text{ (internal stability)}$$

and

$$sw^{IN}(k+1,\xi) - F - f_j(\xi) + \sigma \leq sw^{OUT}(k,\xi) \text{ for all } j \notin A \text{ (external stability).}$$

If a set of Southern country members satisfies both internal and external stability conditions then it is called a stable FTA. Extending the proof by d'Aspremont et al. (1983, Theorem), we can show that there always exists a stable FTA.

Proposition 1. For all $\xi \in [0,1]$ and all $\sigma \geq 0$, there exists a stable FTA.

Proof. First note $f_1(\xi) \leq f_2(\xi) \leq ... \leq f_m(\xi)$ for all $\xi \in [0,1]$ by assumption. Thus, if $sw^{IN}(k,\xi) - F - f_k(\xi) + \sigma \geq sw^{OUT}(k-1,\xi)$ holds then $sw^{IN}(k,\xi) - F - f_{k'}(\xi) + \sigma \geq sw^{OUT}(k-1,\xi)$ holds for all $k' \leq k$. And if $sw^{IN}(k+1,\xi) - F - f_k(\xi) + \sigma \leq sw^{OUT}(k,\xi)$ holds then $sw^{IN}(k+1,\xi) - F - f_{k'}(\xi) + \sigma \leq sw^{OUT}(k,\xi)$ for all $k' \geq k$.

We will prove the statement by contradiction. Suppose that there is no stable FTA. We will use an induction argument.

1. Start with $k = 0$. If $sw^{IN}(1,\xi) - F - f_1(\xi) + \sigma \leq sw^{OUT}(0,\xi)$, then $k = 0$ is a stable FTA. Since there is no stable FTA, we have $sw^{IN}(1,\xi) - F - f_1(\xi) + \sigma \leq sw^{OUT}(0,\xi)$.

2. For $k \geq 1$, suppose that $sw^{IN}(k',\xi) - F - f_{k'}(\xi) + \sigma > sw^{OUT}(k'-1,\xi)$ holds for all $k' \leq k$. This implies $sw^{IN}(k,\xi) - F - f_k(\xi) + \sigma > sw^{OUT}(k-1,\xi)$. If $sw^{IN}(k+1,\xi) - F - f_{k+1}(\xi) + \sigma \leq sw^{OUT}(k,\xi)$, then $A = \{1,...,k\}$ is a stable FTA. Thus, we have $sw^{IN}(k+1,\xi) - F - f_{k+1}(\xi) + \sigma > sw^{OUT}(k,\xi)$. By induction hypothesis $sw^{IN}(k',\xi) - F - f_{k'}(\xi) + \sigma > sw^{OUT}(k'-1,\xi)$ holds for all $k' \leq k$, this implies that $sw^{IN}(k',\xi) - F - f_{k'}(\xi) + \sigma > sw^{OUT}(k'-1,\xi)$ holds for all $k' \leq k+1$.

3. By induction, $sw^{IN}(k',\xi) - F - f_{k'}(\xi) + \sigma > sw^{OUT}(k'-1,\xi)$ holds for all $k' \leq m$. This implies that $A = S$ is internally stable. Since there is no more Southern country, we conclude that $A = S$ is a stable FTA.

This is a contradiction.□

With general functional forms, it is hard to make general statements besides the existence of equilibrium, so we will adopt linear demand functions to describe the optimal FTA participation rule for the Northern country in the next section.

4 Optimal FTA Rules

Here, we allow the Northern country to set the FTA rule, and Southern countries can passively decide whether or not they will participate. We will assume that the Northern country can choose the enforcement level ξ of the usage of the clean technology and a sign-up subsidy σ for FTA participation. We will use linear demand functions so that we can discuss optimal policy mix.

4.1 Linear Demand Functions

Here, we assume that the Northern country has the following inverse demand function: $P(Q) = 1 - Q$, and each Southern country has $p(q) = a - bq$. We have the following basic results (the proof is in Appendix A).

Lemma 1. Suppose that there are k Southern countries in the FTA. The equilibrium total output in the Northern market, the Northern country's output, the Southern FTA and non-FTA country's export to the Northern market, and the Northern country's equilibrium consumer surplus CS are

$$\bar{Q}(k) = \sum_{i=0}^{m} Q_i(k) = \frac{(m+1) - (c_0 + kc_C + (m-k)(c_D + \tau))}{m+2},$$

$$Q_0(k) = \frac{1}{m+2}\left\{1 + (kc_C + (m-k)(c_D+\tau)) - (m+1)c_0\right\},$$

$$Q_C(k) = \frac{1 + c_0 - (m-k+2)c_C + (m-k)(c_D+\tau)}{m+2},$$

$$Q_D(k) = \frac{1 + c_0 + kc_C - (k+2)(c_D+\tau)}{m+2},$$

$$CS(k) = \frac{\left[(m+1) - (c_0 + kc_C + (m-k)(c_D+\tau))\right]^2}{2(m+2)^2},$$

respectively. Profits from the Northern market earned by firms in the Northern country, Southern FTA country (with the clean technology), and Southern non-FTA country (with the dirty technology) are

$$\Pi_0(k) = \left(\frac{1}{m+2}\right)^2 \left[1 - (m+1)c_0 + kc_C + (m-k)(c_D+\tau)\right]^2,$$

$$\Pi_C(k) = \left(\frac{1}{m+2}\right)^2 \left[1 + c_0 - (m-k+2)c_C + (m-k)(c_D+\tau)\right]^2,$$

$$\Pi_D(k) = \left(\frac{1}{m+2}\right)^2 \left[1 + c_0 + kc_C - (k+2)(c_D+\tau)\right]^2,$$

respectively. Domestic outputs, profits, and consumer surpluses in FTA and non-FTA Southern countries are $q_C = \frac{a-c_C}{2b}$, $\pi_C = \frac{(a-c_C)^2}{4b}$, $cs_C = \frac{(a-c_C)^2}{8b}$, and $q_D = \frac{a-c_D}{2b}$, $\pi_D = \frac{(a-c_D)^2}{4b}$,

$cs_D = \frac{(a-c_D)^2}{8b}$, respectively. Finally, the amount of equilibrium total emissions is

$$\begin{aligned} E(k,\xi) = & \left(2e_D - e_C\right)\left(\frac{m+1}{m+2} - \frac{c_0 + kc_C + (m-k)\left(c_D+\tau\right)}{m+2}\right) \\ & - \left(e_D - e_C\right)\left(1-c_C\right) + e_D\left\{k\frac{a-c_C}{2b} + (m-k)\,\frac{a-c_D}{2b}\right\} \\ & - \left(e_D - e_C\right)\left[\frac{1+c_0+kc_C+(m-k)\left(c_D+\tau\right)-(m+2)\,c_0}{m+2}\right] \\ & - \left(e_D - e_C\right)k\xi\left\{\frac{1+c_0+kc_C+(m-k)c_D-(m+2)\,c_C}{m+2} + \frac{a-c_C}{2b}\right\}. \end{aligned}$$

With these basic results, we can analyze the optimal FTA rule for the Northern country. The Northern country can choose a policy combination, the enforcement level $\xi \in [0,1]$, and a sign-up subsidy $\sigma \geq 0$ to the participants of the FTA from Southern countries in order to maximize its social welfare.

$$SW(k,\xi,\sigma) = CS(k) + \Pi_0(k) + \tau\,(m-k)\,Q_D(k) - k\sigma - d_N E(k,\xi) \tag{7}$$

In order to find the optimal FTA policy for the Northern country, we can use the following two-step procedure. First, for each $k = 1,...,m$, find an optimal combination of policies (ξ^k,σ^k) by solving the following problem:

$$(\xi^k,\sigma^k) \in \arg\max_{\xi,\sigma} SW(k,\xi,\sigma) \quad s.t. \quad sw^{IN}(k,\xi) - F - f_k(\xi) + \sigma \geq sw^{OUT}(k-1,\xi). \tag{8}$$

Second, choose the optimal size of an FTA k:

$$k^* = \arg\max_{k} SW(k,\xi^k,\sigma^k).$$

Then, $\left(\xi^{k^*},\sigma^{k^*}\right)$ is the optimal policy that implements a size k^* FTA. *Recall that τ is an uncontrollable variable (see footnote 5).* It is easy to see that a prohibitive tariff is optimal as long as there is at least one Southern FTA member, and it also minimizes non-FTA countries' emissions since it prohibits their access to the Northern market.

In the first step of the analysis, we rewrite the welfare maximization problem (8).

Lemma 2. The constraint of (8) with equality can be written as

$$\begin{aligned}
\sigma(k,\xi) = & -\frac{3\left(a-c_C\right)^2}{8b}+\frac{3\left(a-c_D\right)^2}{8b}+F+f_k(\xi) \\
& -\left(\frac{1}{m+2}\right)^2(m-1)(-c_C+(c_D+\tau)) \\
& \times\left\{2\left(1+c_0\right)-(m-2k+3)\,c_C+(m-2k-1)\left(c_D+\tau\right)\right\} \\
& +d_S\left[\left(3e_D-2e_C\right)\left(\frac{-c_C+\left(c_D+\tau\right)}{m+2}\right)-e_D\left\{-\frac{a-c_C}{2b}+\frac{a-c_D}{2b}\right\}\right. \\
& -\left(e_D-e_C\right)\xi\left\{\frac{1+c_0+kc_C+(m-k)\left(c_D+\tau\right)-(m+2)\,c_C}{m+2}+\frac{a-c_C}{2b}\right\} \\
& \left.+\left(e_D-e_C\right)(k-1)\,\xi\left\{\frac{-c_C+\left(c_D+\tau\right)}{m+2}\right\}\right]
\end{aligned}$$

This implies $\frac{\partial\sigma}{\partial k}>0$ and the constraint gets tighter as k increases. Substituting this formula into (7), we can convert (8) into an unconstrained maximization problem.

Proposition 2. Under linear demand, we have $1\geq\xi_1^*\geq\xi_2^*\geq...\geq\xi_m^*\geq0$ with strict inequalities $\xi_{k-1}^*>\xi_k^*>\xi_{k+1}^*$ for all ks with an interior solution $1>\xi_k^*>0$.

Proof. Problem (8) can be written as

$$SW(k,\xi,\sigma(k,\xi))=CS(k)+\Pi_0(k)+\tau\,(m-k)\,Q_D(k)-k\sigma(k,\xi)-d_NE(k,\xi)$$

Thus, given k, the social optimum ξ_k^* is characterized by

$$k\frac{\partial\sigma}{\partial\xi}+d_N\frac{\partial E}{\partial\xi}=0.$$

Rewriting this, we obtain

$$\begin{aligned}
f_k'(\xi_k^*)=\left(e_D-e_C\right) & \left[\left(d_N+d_S\right)\left\{\frac{1+c_0+kc_C+(m-k)\left(c_D+\tau\right)-(m+2)\,c_C}{m+2}+\frac{a-c_C}{2b}\right\}\right. \\
& \left.-(k-1)\,d_S\left(\frac{-c_C+\left(c_D+\tau\right)}{m+2}\right)\right].
\end{aligned}$$

Since $(c_D+\tau)>c_C$, the RHS is decreasing in k. Since $f_k''(\xi)>0$ and $f_k'(\xi)\geq f_{k-1}'(\xi)$ for all ξ, we conclude $\xi_k^*<\xi_{k-1}^*$ holds for all k as long as they are interior solutions.□

This proposition shows that there is a tradeoff between the number of Southern participants and the level of enforcement. Although it is hard to analyze whether or not equilibrium

σ increases monotonically without specifying f_k functions, it is quite natural to assume that the total subsidy payment $k\sigma_k^* < (k+1)\,\sigma_{k+1}^*$ holds for all k as long as solutions are interior. Thus, the Northern country cannot expand the membership of the FTA too much, since such an expansion means that the program becomes more costly and the level of enforcement goes down.

5 A Numerical Example

In this section, we provide a numerical example in order to see the quantitative properties of our model. We specify f_k function in the following manner:

$$f_k(\xi) = \frac{1}{2}\beta_k \xi^2,$$

where $\beta_1 \leq \beta_2 \leq ... \leq \beta_m$. This formulation satisfies $f_k'(0) = 0$ while $f_k(1) = \beta_k < \infty$. Then, ξ_k^* is written as

$$\xi_k^* = \frac{(e_D - e_C)}{\beta_k}\left[(d_N + d_S)\left\{\frac{1 + c_0 + kc_C + (m-k)(c_D + \tau) - (m+2)\,c_C}{m+2} + \frac{a - c_C}{2b}\right\} - (k-1)\,d_S\left(\frac{-c_C + (c_D + \tau)}{m+2}\right)\right]$$

if the RHS is less than 1, and $\xi_k^* = 1$ otherwise.

We set the parameter values as $m = 10$, $c_0 = 0.25$, $c_C = 0.2$, $c_D = 0.15$, $\tau = 0.1$, $a = 0.3$, $b = 1$, $d_N = 0.5$, $d_S = 0$, $e_D = 0.3$, and $e_C = 0.1$. We also assume that $\beta_k = \beta = 0.017$ for all k, and $F = 0$.

This numerical example is not the most realistic one, but it provides a good understanding of the model. Our main findings are as follows.

(1) Starting from no free trade agreement, if one Southern country joins the FTA, it gets a high market share of the Northern market. Thus, if only one country joins the agreement, a high enforcement rate can be imposed only with a small sign-up subsidy. (Depending on parameter values, $\xi = 1$ and $\sigma = 0$ can occur very easily).

(2) In this set of parameter values, tariff revenue plays a strong role in the Northern country's social welfare; as a result, it can care less about FTA.

Table 1: A Numerical Example

k	0	1	2	3	4	5	6	7	8	9	10
Q	0.6875	0.69167	0.69583	0.7	0.70417	0.70833	0.7125	0.71667	0.72083	0.725	0.79217
P	0.3125	0.30833	0.30417	0.3	0.29583	0.29167	0.2875	0.28333	0.27917	0.275	0.27083
Q_0	0.0625	0.05833	0.05417	0.05	0.04583	0.04167	0.0375	0.03333	0.02917	0.025	0.02083
Q_C	-	0.10833	0.10417	0.1	0.09583	0.09167	0.0875	0.08333	0.07917	0.075	0.07083
Q_D	0.0625	0.05833	0.05417	0.05	0.04583	0.04167	0.0375	0.03333	0.02917	0.025	0.02083
Π_0	0.00391	0.0034	0.00293	0.0025	0.0021	0.00174	0.00141	0.00111	0.00085	0.00063	0.00043
Π_C	-	0.01174	0.01085	0.01	0.00918	0.0084	0.00766	0.00694	0.00627	0.00563	0.00502
Π_D	0.00391	0.0034	0.00293	0.0025	0.0021	0.00174	0.00141	0.00111	0.00085	0.00063	0.00043
CS	0.23633	0.2392	0.24209	0.245	0.24793	0.25087	0.25383	0.25681	0.2598	0.26281	0.26584
ξ	-	0.93137	0.90686	0.88235	0.85784	0.83333	0.80882	0.78431	0.7598	0.73529	0.71078
E	0.24438	0.22218	0.20263	0.18562	0.17102	0.15872	0.14857	0.14047	0.13429	0.12991	0.12721
σ	-	0.00024	0.00055	0.00078	0.00107	0.00137	0.00168	0.002	0.00233	0.00267	0.00302
TR	0.0625	0.0525	0.04333	0.035	0.0275	0.02083	0.015	0.01	0.00583	0.0025	0
SW	0.18057	0.18378	0.18603	0.18734	*0.18772*	0.18722	0.18586	0.18368	0.18069	0.17695	0.17246

(3) With this set of parameter values, E_k^* is monotonically decreasing in k but the magnitude of marginal reduction in k is decreasing. Note that the level of enforcement ξ_k^* is monotonically decreasing. Thus, depending on parameter values, the movement of total emissions E_k^* can be not monotonic in k. As ξ_k^* decreases, E_k^* can turn back upward. This is because the Northern market is much larger than the Southern market.

(4) The Northern country needs to evaluate the benefits and costs of changing its policies (ξ and σ) to increase Southern countries membership by evaluating CS, Π_0, and TR (tariff revenues), in addition to emissions E. Here, $k = 4$ is the optimal number of Southern countries in the Free Trade Agreement.

(5) Under some parameter values, nonmember Southern countries can be effectively excluded from access to the Northern market (if $P(k) < c_C + \tau$).

Moreover, we can easily see how changes in the enforcement cost, β, the tariff rate, τ, the cost of the clean technology, c_C, and the emission from the dirty technology, e_D, affect the optimal number of the Southern countries participating in the FTA. In Appendix B we show the results of changes in these values ($\beta_k = \beta$ from 0.017 to 0.02, τ from 0.1 to 0.15, c_C from 0.2 to 0.18, and e_D from 0.3 to 0.5), and from them we can find the followings.

(1) If the enforcement efficiency is lower (higher β), the number of FTA members declines because the enforcement of clean-tech implementation is more difficult. Therefore, it would be better to exclude a state with a high probability of cheating.

(2) The higher tariff rate (τ) increases the number of member states. Whereas the Northern country tries to decrease the number, the Southern countries have more incentive to

become a member to avoid the considerably high tariff rate.

(3) If the clean technology is less costly (lower c_C), more states will join the FTA. Additionally, emissions decline because such reduction will be easier if it is less costly.

(4) An increase in the emission rate (higher e_D) in Southern countries raises the aggregate emissions as long as the number of member states is kept constant. However, these higher emissions induce the Northern country to persuade Southern countries to become members. Thus, the number of member countries adopting the clean technology increases and eventually the aggregate level of emissions declines.

6 Conclusion

In this paper, we analyzed the optimal free trade agreement (FTA) between Northern and Southern countries by explicitly considering the environmental aspects of trade. We first proved the existence of stable free trade agreement. Then we showed that there exists an interior solution of the optimal number of Southern member countries. Although the firms in Southern member countries take advantage of having an access to the Northern market without barriers, they are unwilling to employ clean but costly technology provided by Northern country. Then, Northern country has to propose an FTA sufficiently beneficial to Southern countries in order to enforce the South to implement tighter environmental regulation. Because having an excessive number of participants from Southern countries discourages them to become a member of FTA, it is essential for the North to restrict the memberships of the South while their strict enforcement of emission reduction is required. A quantitative evaluation of FTA policies has also been provided by a numerical example. We demonstrated that, on the one hand, an increase in the emission rate in Southern countries (which may be a result of economic growth) raises the aggregate emissions if the number of member states is kept constant. On the other hand, its overall effect on the aggregate emissions is negative due to the corresponding increase in Southern member countries, which adopt the clean technology.

Apart from the modeling, there might be another political reason to tie a high environmental standard with free trade agreements. Imposing a high environmental standard (enforcement of the clean technology) makes it politically easier for a Northern country to form an FTA with Southern countries (Bill Clinton forced Mexico to satisfy higher environmental standards, for instance.). The number of Southern countries will be reduced as a byproduct, which also helps to pass the bill in Congress/Parliament. In such a case, it might also be interesting to analyze whether a political turnover would affect the number of Southern participants, as well as global emissions. These factors may require further investigation.

Appendix A: Linear Demand

Here, we assume that the Northern country has the following demand function: $P(Q) = 1 - Q$. Firm j's profit maximization problem is

$$\max_{q_j^0} \left(1 - \sum_{i=0}^{m} Q_i\right) Q_j - c_j Q_j.$$

The first order condition is

$$1 - \sum_{i=0}^{m} Q_i - Q_j - c_j = 0.$$

Summing them up, we obtain

$$(m+1) - \left((m+2) \sum_{i=0}^{m} Q_i\right) - \sum_{i=0}^{m} c_i = 0$$

and

$$\bar{Q} = \sum_{i=0}^{m} Q_i = \frac{m+1}{m+2} - \frac{1}{m+2} \sum_{i=0}^{m} c_i.$$

Let $\alpha_C w_N = c_0$, $\alpha_C w_S = c_C$, and $\alpha_D w_S = c_D$. We assume that in the presence of a tariff charged by the Northern country, the marginal cost of using the clean technology in the FTA is lower than the one of using the dirty technology outside of the FTA if they export $c^{OUT} = c_D + \tau > c^{IN} = c_C$ naturally although $c_C > c_D$ holds. The equilibrium output by country j when k Southern countries participate in the FTA is

$$\begin{aligned} Q_j &= \frac{1}{m+2} + \frac{1}{m+2} \sum_{i=0}^{m} c_i - c_j \\ &= \frac{1}{m+2} \left\{1 + (c_0 + k c_C + (m-k)(c_D + \tau)) - (m+2) c_j\right\}. \end{aligned}$$

Thus, the Northern country's output and FTA and non-FTA Southern countries' exports are written as

$$Q_0(k) = \frac{1}{m+2} \left\{1 + (k c_C + (m-k)(c_D + \tau)) - (m+1) c_0\right\},$$

$$Q_C(k) = \frac{1}{m+2} \left[1 + c_0 - (m-k+2) c_C + (m-k)(c_D + \tau)\right],$$

$$Q_D(k) = \frac{1}{m+2} \left[1 + c_0 + k c_C - (k+2)(c_D + \tau)\right],$$

respectively. Since $\Pi_j = Q_j^2$, we have the following

$$\Pi_C(k) = \left(\frac{1}{m+2}\right)^2 \left[1 + c_0 - (m-k+2)\, c_C + (m-k)\,(c_D+\tau)\right]^2,$$

$$\Pi_D(k) = \left(\frac{1}{m+2}\right)^2 \left[1 + c_0 + kc_C - (k+2)\,(c_D+\tau)\right]^2.$$

Substituting Q_js and q_js into $E(k,\xi)$, we obtain

$$\begin{aligned}
E(k,\xi) &= e_D\bar{Q}(k) - (e_D - e_C)\, Q_0(k) + e_D\left\{kq_C + (m-k)\, q_D\right\} - (e_D - e_C)\, k\xi \left\{Q_C(k) + q_C\right\} \\
&= (2e_D - e_C)\left(\frac{m+1}{m+2} - \frac{c_0 + kc_C + (m-k)\,(c_D+\tau)}{m+2}\right) \\
&- (e_D - e_C)\,(1 - c_C) + e_D\left\{k\frac{a-c_C}{2b} + (m-k)\,\frac{a-c_D}{2b}\right\} \\
&- (e_D - e_C)\left[\frac{1 + c_0 + kc_C + (m-k)\,(c_D+\tau) - (m+2)\, c_0}{m+2}\right] \\
&- (e_D - e_C)\, k\xi\left\{\frac{1 + c_0 + kc_C + (m-k)\,(c_D+\tau) - (m+2)\, c_C}{m+2} + \frac{a-c_C}{2b}\right\}.
\end{aligned}$$

Thus, we have

$$\begin{aligned}
&E(k,\xi) - E(k-1,\xi) \\
&= (3e_D - 2e_C)\left(\frac{-c_C + (c_D+\tau)}{m+2}\right) + e_D\left\{\frac{a-c_C}{2b} - \frac{a-c_D}{2b}\right\} \\
&- (e_D - e_C)\, k\xi\left\{\frac{1 + c_0 + kc_C + (m-k)\,(c_D+\tau) - (m+2)\, c_C}{m+2} + \frac{a-c_C}{2b}\right\} \\
&+ (e_D - e_C)\,(k-1)\,\xi\left\{\frac{1 + c_0 + (k-1)\, c_C + (m-k+1)\,(c_D+\tau) - (m+2)\, c_C}{m+2} + \frac{a-c_C}{2b}\right\} \\
&= (3e_D - 2e_C)\left(\frac{-c_C + (c_D+\tau)}{m+2}\right) - e_D\left\{-\frac{a-c_C}{2b} + \frac{a-c_D}{2b}\right\} \\
&- (e_D - e_C)\,\xi\left\{\frac{1 + c_0 + kc_C + (m-k)\,(c_D+\tau) - (m+2)\, c_C}{m+2} + \frac{a-c_C}{2b}\right\} \\
&+ (e_D - e_C)\,(k-1)\,\xi\left\{\frac{-c_C + (c_D+\tau)}{m+2}\right\}.
\end{aligned}$$

We can interpret the above formula. The first term is an indirect effect of equilibrium output that increases in the Northern market by giving another Southern country an access to the Northern market. The second term is an effect of output reduction in a new Southern entrant country. The third term is the direct effect of reducing emissions by having another country with clean technology in the Northern market. The fourth term represents an indirect effect of reductions in clean technology production in the existing $k-1$ Southern member countries crowded out by the kth Southern country's participation.

Southern country j's social welfare is written for two different cases: being a member or a nonmember of the FTA. Southern countries' social welfare can be written as

$$\begin{aligned} sw^{OUT}(k,\xi) &= cs_D + \Pi_D(k) + \pi_D - d_S E(k,\xi) \\ &= \frac{(a-c_D)^2}{8b} + \left(\frac{1}{m+2}\right)^2 [1 + c_0 + kc_C - (k+2)(c_D+\tau)]^2 + \frac{(a-c_D)^2}{4b} \\ &- d_S E(k,\xi) \end{aligned}$$

if $j \notin A$, and

$$\begin{aligned} sw^{IN}(k,\xi) &= cs_C + \Pi_C(k) + \pi_C + (1-\xi)(\alpha_C - \alpha_D)\, w_S (Q_C + q_C) - d_S E(k,\xi) \\ &= \frac{(a-c_C)^2}{8b} + \left(\frac{1}{m+2}\right)^2 [1 + c_0 - (m-k+2)\, c_C + (m-k)(c_D+\tau)]^2 \\ &+ \frac{(a-c_C)^2}{4b} - d_S E(k,\xi) \end{aligned}$$

if $j \in A$.

This implies

$$\begin{aligned} & sw^{IN}(k,\xi) - sw^{OUT}(k-1,\xi) \\ &= \frac{(a-c_C)^2}{8b} + \left(\frac{1}{m+2}\right)^2 [1 + c_0 - (m-k+2)\, c_C + (m-k)(c_D+\tau)]^2 + \frac{(a-c_C)^2}{4b} \\ &- d_S E(k,\xi) - \frac{(a-c_D)^2}{8b} - \left(\frac{1}{m+2}\right)^2 [1 + c_0 + (k-1)\, c_C - (k+1)(c_D+\tau)]^2 \\ &- \frac{(a-c_D)^2}{4b} + d_S E(k-1,\xi) \\ &= \frac{3\,(a-c_C)^2}{8b} - \frac{3\,(a-c_D)^2}{8b} \\ &+ \left(\frac{1}{m+2}\right)^2 (m-1)(c_D+\tau-c_C) \times \{2\,(1+c_0) - (m-2k+3)\, c_C + (m-2k-1)(c_D+\tau)\} \\ &+ d_S(E(k-1,\xi) - E(k,\xi)). \end{aligned}$$

Northern country 0 can choose a policy combination: the enforcement level $\xi \in [0,1]$ and a sign-up subsidy $\sigma \geq 0$ to the participants of FTA from Southern countries. In order to find the optimal FTA policy for the Northern country, we can use the following procedure. First for each $k = 1, ..., m$, find an optimal combination of policies (ξ^k, σ^k) by solving the problem:

$$(\xi^k, \sigma^k) \in \arg\max_{\xi,\sigma} SW(k, \xi, \sigma) \quad s.t. \quad sw^{IN}(k, \xi) - F - f_k(\xi) + \sigma \geq sw^{OUT}(k-1, \xi).$$

For describing the binding constraint of the above problem, we express the subsidy amount as a function of ξ and k:

$$\begin{aligned}
\sigma &= s(\xi, k) \\
&= -sw^{IN}(k, \xi) + F(0) + f(\xi) + sw^{OUT}(k-1, \xi) \\
&= \frac{3\,(2a - c_C - c_D)\,(c_C - c_D)}{8b} \\
&- (1-\xi)\,(c_C - c_D)\left[\frac{1 + c_0 - (m-k+2)\,c_C + (m-k)\,(c_D + \tau)}{m+2} + \frac{a - c_C}{2b}\right] \\
&- d_S\left(\frac{1}{m+2}\right)^2 (m-1)(c_D + \tau - c_C) \times \{2\,(1 + c_0) + (m - 2k + 1)\,(c_D + \tau - c_C)\} \\
&+ F + f_k(\xi) + d_S E(k, \xi).
\end{aligned}$$

Problem (8) can be written as

$$SW(k, \xi, \sigma(k, \xi)) = CS(k) + \Pi_0(k) + \tau\,(m-k)\,Q_D(k) - k\sigma(k, \xi) - d_N E(k, \xi).$$

Thus, given k, the social optimum ξ_k^* is characterized by

$$k\frac{\partial \sigma}{\partial \xi} + d_N\frac{\partial E}{\partial \xi} = 0.$$

Thus, we have

$$\begin{aligned}
&k f_k'(\xi_k^*) - d_S\,(e_D - e_C)\,k\left\{\frac{1 + c_0 + kc_C + (m-k)\,(c_D + \tau) - (m+2)\,c_C}{m+2} + \frac{a - c_C}{2b}\right\} \\
&+ d_S\,(e_D - e_C)\,k\,(k-1)\left\{\frac{-c_C + (c_D + \tau)}{m+2}\right\} \\
&- d_N\,(e_D - e_C)\,k\left\{\frac{1 + c_0 + kc_C + (m-k)\,(c_D + \tau) - (m+2)\,c_C}{m+2} + \frac{a - c_C}{2b}\right\} \\
&= 0.
\end{aligned}$$

Rewriting this, we obtain

$$f_k'(\xi_k^*) = (e_D - e_C)\left[(d_N + d_S)\left\{\frac{1 + c_0 + kc_C + (m-k)(c_D + \tau) - (m+2)c_C}{m+2} + \frac{a - c_C}{2b}\right\}\right.$$
$$\left. - (k-1)\, d_S\left(\frac{-c_C + (c_D + \tau)}{m+2}\right)\right].$$

Since $(c_D + \tau) > c_C$, the RHS is decreasing in k. Since $f_k''(\xi) > 0$ and $f_k'(\xi) \geq f_{k-1}'(\xi)$ for all ξ, we conclude $\xi_k^* < \xi_{k-1}^*$ holds for all k as long as they are interior solutions.

Appendix B: More numerical examples

Table A1: Lower Efficiency of Enforcement: $\beta = \beta_k = 0.02$

k	0	1	2	3	4	5	6	7	8	9	10
$\bar{Q}$	0.6875	0.69167	0.69583	0.7	0.70417	0.70833	0.7125	0.71667	0.72083	0.725	0.72917
P	0.3125	0.30833	0.30417	0.3	0.29583	0.29167	0.2875	0.28333	0.27917	0.275	0.27083
Q_0	0.0625	0.05833	0.05417	0.05	0.04583	0.04167	0.0375	0.03333	0.02917	0.025	0.02083
Q_C	-	0.10833	0.10417	0.1	0.09583	0.09167	0.0875	0.08333	0.07917	0.075	0.07083
Q_D	0.0625	0.05833	0.05417	0.05	0.04583	0.04167	0.0375	0.03333	0.02917	0.025	0.02083
Π_0	0.00391	0.0034	0.00293	0.0025	0.0021	0.00174	0.00141	0.00111	0.00085	0.00063	0.00043
Π_C	-	0.01174	0.01085	0.01	0.00918	0.0084	0.00766	0.00694	0.00627	0.00563	0.00502
Π_D	0.00391	0.0034	0.00293	0.0025	0.0021	0.00174	0.00141	0.00111	0.00085	0.00063	0.00043
CS	0.23633	0.2392	0.24209	0.245	0.24793	0.25087	0.25383	0.25681	0.2598	0.26281	0.26584
ξ	1	0.79167	0.77083	0.75	0.72917	0.70833	0.6875	0.66667	0.64583	0.625	0.60417
E	0.24438	0.22544	0.20876	0.19423	0.18176	0.17123	0.16254	0.15559	0.15027	0.14648	0.14411
σ	-	-	-	0.00012	0.00046	0.0008	0.00115	0.00151	0.00188	0.00226	0.00264
TR	0.0625	0.0525	0.04333	0.035	0.0275	0.02083	0.015	0.01	0.00583	0.0025	-
SW	0.18055	0.18238	0.18398	*0.18502*	0.18482	0.18383	0.18206	0.17955	0.17632	0.17239	0.16779

Table A2: Higher Tariff Rate: $\tau = 0.15$

k	0	1	2	3	4	5	6	7	8	9	10
$\bar{Q}$	0.64583	0.65417	0.6625	0.67083	0.67917	0.6875	0.69583	0.70417	0.7125	0.72083	0.72917
P	0.35417	0.34583	0.3375	0.32917	0.32083	0.3125	0.30417	0.29583	0.2875	0.27917	0.27083
Q_0	0.10417	0.09583	0.0875	0.07917	0.07083	0.0625	0.05417	0.04583	0.0375	0.02917	0.02083
Q_C	-	0.14583	0.1375	0.12917	0.12083	0.1125	0.10417	0.09583	0.0875	0.07917	0.07083
Q_D	0.05417	0.04583	0.0375	0.02917	0.02083	0.0125	0.00417	-	-	-	-
Π_0	0.01085	0.00918	0.00766	0.00627	0.00502	0.00391	0.00293	0.0021	0.00141	0.00085	0.00043
Π_C	-	0.02127	0.01891	0.01668	0.0146	0.01266	0.01085	0.00918	0.00766	0.00627	0.00502
Π_D	0.00293	0.0021	0.00141	0.00085	0.00043	0.00016	0.00002	-	-	-	-
CS	0.20855	0.21397	0.21945	0.22501	0.23063	0.23633	0.24209	0.24793	0.25383	0.2598	0.26584
ξ	1	1	1	1	1	0.95588	0.90686	0.85784	0.80882	0.7598	0.71078
E	0.22354	0.19432	0.16844	0.14589	0.12667	0.11612	0.11081	0.10976	0.11247	0.11845	0.12721
σ	-	-	-	-	-	-	-	-	-	0.00122	0.0024
TR	0.08125	0.06188	0.045	0.03063	0.01875	0.00938	0.0025	-	-	-	-
SW	0.18888	0.18786	0.18789	0.18896	0.19107	0.19155	0.19212	0.19514	*0.19900*	0.19045	0.17871

Table A3: Cheaper Clean Technology: $c_C = 0.18$

k	0	1	2	3	4	5	6	7	8	9	10
$\bar{Q}$	0.6875	0.69333	0.69917	0.705	0.71083	0.71667	0.7225	0.72833	0.73417	0.74	0.74583
P	0.3125	0.30667	0.30083	0.295	0.28917	0.28333	0.2775	0.27167	0.26583	0.26	0.25417
Q_0	0.0625	0.05667	0.05083	0.045	0.03917	0.03333	0.0275	0.02167	0.01583	0.01	0.00417
Q_C	-	0.12667	0.12083	0.115	0.10917	0.10333	0.0975	0.09167	0.08583	0.08	0.07417
Q_D	0.0625	0.05667	0.05083	0.045	0.03917	0.03333	0.0275	0.02167	0.01583	0.01	0.00417
Π_0	0.00391	0.00321	0.00258	0.00203	0.00153	0.00111	0.00076	0.00047	0.00025	0.0001	0.00002
Π_C	-	0.01604	0.01460	0.01323	0.01192	0.01068	0.00951	0.00840	0.00737	0.0064	0.0055
Π_D	0.00391	0.00321	0.00258	0.00203	0.00153	0.00111	0.00076	0.00047	0.00025	0.0001	0.00002
CS	0.23633	0.24036	0.24442	0.24851	0.25264	0.25681	0.261	0.26523	0.26950	0.2738	0.27813
ξ	1	1	1	1	0.9951	0.96078	0.92647	0.89216	0.85784	0.82353	0.78922
E	0.24438	0.21774	0.19344	0.17147	0.15229	0.13891	0.12891	0.12204	0.11807	0.11675	0.11784
σ	-	-	-	-	-	-	-	0.00049	0.00117	0.00186	0.00257
TR	0.0625	0.051	0.04067	0.0315	0.0235	0.01667	0.011	0.0065	0.00317	0.001	0
SW	0.18055	0.1857	0.19095	0.1963	0.20153	0.20513	*0.2083*	0.20772	0.2045	0.19974	0.19355

Table A4: Higher Emission Rate: $e_D = 0.5$

k	0	1	2	3	4	5	6	7	8	9	10
$\bar{Q}$	0.6875	0.69333	0.69917	0.705	0.71083	0.71667	0.7225	0.72833	0.73417	0.74	0.74583
P	0.31250	0.30667	0.30083	0.295	0.28917	0.28333	0.2775	0.27167	0.26583	0.26	0.25417
Q_0	0.0625	0.05667	0.05083	0.045	0.03917	0.03333	0.0275	0.02167	0.01583	0.01	0.00417
Q_C	-	0.12667	0.12083	0.115	0.10917	0.10333	0.0975	0.09167	0.08583	0.08	0.07417
Q_D	0.0625	0.05667	0.05083	0.045	0.03917	0.03333	0.0275	0.02167	0.01583	0.01	0.00417
Π_0	0.00391	0.00321	0.00258	0.00203	0.00153	0.00111	0.00076	0.00047	0.00025	0.0001	0.00002
Π_C	-	0.01604	0.0146	0.01323	0.01192	0.01068	0.00951	0.0084	0.00737	0.0064	0.0055
Π_D	0.00391	0.00321	0.00258	0.00203	0.00153	0.00111	0.00076	0.00047	0.00025	0.0001	0.00002
CS	0.23633	0.24036	0.24442	0.24851	0.25264	0.25681	0.261	0.26523	0.26950	0.27380	0.27813
ξ	1	1	1	1	1	1	1	1	1	1	1
E	0.40313	0.35011	0.30177	0.25809	0.21908	0.18474	0.15506	0.13005	0.10971	0.09403	0.08302
σ	-	-	-	-	-	-	0.00004	0.00079	0.00154	0.00229	0.00304
TR	0.0625	0.051	0.04067	0.0315	0.0235	0.01667	0.011	0.0065	0.00317	0.001	-
SW	0.10117	0.11951	0.13678	0.15299	0.16813	0.18221	0.19497	0.20164	0.20575	*0.20729*	0.20627

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