Free Trade Agreements with Environmental Provisions Between Asymmetric Countries: Transfer of Clean Technology and Enforcement

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Abstract

countries to employ them because these technologies tend to be too costly to be implemented for developing countries despite the recent dramatic improvements in the cost-effectiveness of clean technologies. The Technology and Innovation Report 2021 at the United Nations Conference on Trade and Development reported several challenges of adapting new technologies by developing countries: digital divides, inadequate infrastructure, and skill shortages make using new clean technologies more expensive than dirty technologies.[2] Even if developed countries successfully transfer clean technologies to developing countries, it does not necessarily follow that developing countries would employ them. Firms in a developing country may still employ low-cost dirty technologies if the government's enforcement level of its environmental policies is low. In such a case, developed countries must also help southern governments monitor and enforce the environmental policies.[3]

In this paper, we develop a new theoretical model for a free trade agreement (FTA) with environmental provisions between developed (northern) and developing (southern) countries, taking the issues listed above. Unlike most existing papers that deal with stable multinational environmental agreements (MEAs) among symmetric countries, we assume that there is one northern country and multiple southern countries and that the northern country can sign an FTA with any number of southern countries. We consider high-marginal-cost clean and cheap dirty technologies that produce manufacturing goods to be traded; the northern country has clean technology, and the southern countries have only dirty technology without free trade agreements with the northern country. If a southern country establishes an FTA with the northern country, the clean technology becomes available. However, without being sufficiently

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enforced, the southern firms have an incentive to use the cheaper dirty technology as a result of their optimization. Thus, southern countries may not want to participate in an FTA with the northern country if its environmental provision requires a strict enforcement of clean technology unless access to the northern market is sufficiently lucrative or participating in the FTA comes with monetary support from the northern country.

We first show that for any given level of enforcement and monetary support, there is a stable free trade agreement for southern countries, in the sense that (i) no southern insider wants to quit the FTA unilaterally, and (ii) no southern outsider wants to participate in the FTA unilaterally (Proposition 1). This stability notion was first introduced by d'Aspremont et al. (1983) to analyze cartels and is widely used by environmental economists (see Barrett 1994). Note that Proposition 1 assures neither that the stable FTA is nontrivial (at least one southern country participates in the FTA), nor that the northern country wants to have an FTA. This is because Proposition 1 is for any arbitrary combination of enforcement and monetary support policies. Thus, we try to characterize the optimal FTA policy for the northern country, then find the conditions for a nontrivial optimal FTA.

Unfortunately, it is generally difficult to characterize the optimal FTA for the northern country, so we specify functional forms. Using linear demand functions, we first characterize the optimal policies for each number of southern countries in the FTA and find that the enforcement level of the clean technology use (the fraction of production that uses the clean technology) goes down as the size of the FTA increases. Second, we characterize the optimal number of southern countries in the FTA by maximizing the northern country's payoff (Proposition 2). Proposition 3 provides sufficient conditions for the optimal FTA being nontrivial. This implies that the northern country has an incentive to form an FTA with environmental provisions with southern countries when (a) the clean technology is significantly superior to the dirty technology for reducing emissions, and (b) the northern country values reductions in emissions sufficiently.

With Proposition 2, we can easily see that there is a trade-off between having more southern countries in the FTA and the level of enforcement. If the number of southern countries in the FTA is small, these countries receive great benefits from being included in the FTA (i.e., by having exclusive accesses to a lucrative northern market), and thus they are willing to enforce the high-cost clean technology while demanding fewer transfers. Including more southern countries in the FTA, the enforcement level will decrease, and they may demand more transfers. Additionally, with more southern members, the northern country's consumer surplus increases while its domestic firm's profit and its tariff revenue decrease. Analyzing the optimal size of an FTA requires more specifications. Moreover, we do not know how the total level of emissions would be affected by an increase in the number of southern countries in the FTA, because the enforcement level for the FTA members decreases while the number of southern countries increases. Additionally, as the southern membership increases, the total transfers become increasingly costly for the northern country. As all of these factors are important and it is difficult to obtain 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.

With a numerical example, we confirm that these considerations play important roles in evaluating FTA policies. Setting the tariff rate at the optimal level (without envisouthern countries. Comparative static analyses of the numerical example demonstrate that if the number of member countries is kept constant, an increase in emissions from southern countries (as their dirty technology worsens) raises the aggregate emissions. However, this also shows that once the number of member countries is endogenized, its overall effect on the aggregate emissions can be negative, due to the subsequent increase in the number of southern participants that adopt clean technologies.

The rest of the paper is organized as follows. The following subsection provides a brief literature review. Section 2 presents the model and preliminary analysis, and Section 3 analyzes stable FTAs in the general model. Section 4 further analyzes the optimal stable FTAs using linear demand, and Section 5 is devoted to a numerical analysis. Section 6 concludes.

1.1 A Brief Literature Review

In this subsection, we first review four important issues related to our study: FTA formation between developed and developing countries, FTAs with environmental provisions between northern and southern countries, clean technology transfers, and their enforcement. Then, we also review several industrial organization papers that are directly related to our modeling strategy.

Until the beginning of the 21st century, FTAs were signed mostly between developed or developing countries and very few between developed and developing countries. In order to explain this fact, Das and Ghosh (2006) considered a world economy consisting of asymmetric countries, specifically, a world economy with two developed countries in the north and two developing countries in the south, and analyzed what kind of FTAs would be formed. Using a stylized Cournot oligopoly model, they showed that high-income northern countries are more willing to form an FTA between themselves. In contrast, a low-income southern country will want to be a partner with a high-income northern country, but since the northern country will gain little benefits, the southern countries are likely to form an FTA between them as leftovers.[4] Thus, in such North-South type models, it has been theoretically shown that an FTA is more likely to be formed between the two northern or the two southern countries, and less likely to be formed between a northern and a southern countries.[5]

In reality, as noted in the introduction, North-South FTAs have increased in recent years. This fact, as Limão (2007) pointed out, seems to illustrate the importance of considering factors other than gains from trade when analyzing North-South FTAs. This perception is now shared by many researchers and is widely discussed as a matter of "deep integration," which is an FTA with various non-tariff issues such as the environment, labor, technology standard, and intellectual property rights. For example, Maggi and Ossa (2020,2021) discussed the political economy of deep integration and suggested that the welfare analysis of such deep integrations would be very complicated. Our research interests are in line with the literature on deep integration, but we are specifically interested in the effects of clean technology transfer and imperfect enforcement under FTAs. The importance of technology upgrades induced by an FTA in developing countries was empirically investigated by Gutierréz and Teshima (2018). Pointing out that the adoption of superior clean technology can be associated with a reduction in abatement expenditure, they analyzed Mexican data on NAFTA and found that these two phenomena occur simultaneously in Mexico.

Many theoretical and empirical studies have investigated how FTAs affect the trade barriers of member countries to nonmember countries as external trade barriers. On the empirical

[4] Many papers investigated whether or not subsequent formations of FTAs and customs unions will lead to the global free trade (for example, Yi 1996, Goyal and Joshi 2006, Furusawa and Konishi 2007, and Daisaka and Furusawa 2014). However, these papers mostly assume that countries are ex ante homogenous by employing symmetric oligopoly models, and the results are mixed depending on the formulation of the game and the solution concepts.

[5] See also Missios and Yildiz (2017) and Wang and Zhao (2022) for related analysis using a four-country North-South type model.

front, several authors such as Martinez-Zarzoso and Oueslati (2018), and Brandi et al. (2020)

2 The Model

2.1 The basic structure of the model

In this model, there are one northern country and m southern countries, each of which has a representative consumer who consume a numeraire good and an industrial good. The industrial good is produced competitively. The consumer is endowed with the numeraire good, which is used for production of the industrial good with a constant marginal cost. We assume that the numeraire good is freely tradable.

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 $P(Q)$, whereas the southern countries have identical inverse demand functions for the industrial good $p(q_j)$, where 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.

There are two technologies that produce industrial goods: clean and dirty. Although these two technologies produce the same goods, the clean technology emits less environmental pollutants in production.[8] Northern country 0 always employs clean technology C, whereas southern countries have only dirty technology D initially. Northern country's marginal cost of production using clean technology is denoted by c_0, and each southern country's marginal costs of productions using technologies C and D are denoted by c_C and c_D, respectively. We naturally assume:

(A1) $c_0 > c_C > c_D > 0$.

To produce one unit of an industrial good, clean technology costs more than dirty technology for southern countries. This assumption reflects the challenges

The emissions from producing one unit with clean and dirty technologies are denoted by e_C and e_D, respectively. By definition, we assume:

(A2) $e_D > e_C \quad 0$:

The northern country applies a common tariff rate $\quad > 0$ on imports from southern countries. Unless southern country j has a free trade agreement with the northern country, the tariff rate applies. We fix throughout this study (is not a policy variable).

(A3) $\quad > 0$ is unaffected by the formation of an FTA.

This is because the WTO prohibits increasing tariffs when countries form an FTA and a customs union.[9] The northern and southern countries have a single (monopoly) firm each. Southern country j's export quantity to the northern country 0 is denoted by Q_j and country 0's domestic supply is denoted by Q_0. We do not consider indirect exports via a third country.[10] Thus, the total supply in country 0 is $Q = \sum_{j \in S} Q_j + Q_0$. For simplicity, we assume that the southern countries do not import industrial goods.[11]

2.2 Free trade agreement, environmental provisions, and law enforcement

We consider FTAs with environmental provisions between northern country 0 and some of the southern countries. We denote FTA partners with northern country 0 by set $A \quad S =$

[9] One of the key principles of the WTO is nondiscrimination (Obviously, an FTA is itself discriminatory, but the GATT's Article 24 allows for FTAs and customs unions as long as they do not provide negative externalities to outsiders.). Increasing appears to discriminate outsiders from FTA members, even though it is motivated by a northern country's intention to encourage southern countries to join. See Furusawa and Konishi (2007).

[10] Although an FTA does allow to export via a third country that is a member of the FTA, it is necessary to certify the origin of the goods to apply the adequate tariff rate in the importing country. Thus, in our simple model, we do not need to consider indirect export.

[11] As our main concern lies in environmental pollution from technologies used in production in developing countries, production activities in developed countries using clean technologies are not of great importance. Therefore, we assume away imports of the southern countries from the northern country. A similar assumption is imposed by Limão (2007), where small (developing) countries derive no utility from non-numeraire (industrial) goods to narrow the focus of the analysis.

$\{1, \ldots, m\}$. Country 0 levies no tariff on the imports from countries $j \in A$; following the WTO's requirements for forming FTAs. With the environmental provisions accompanied with FTAs, we assume that countries $j \in A$ must accept a clean technology C transferred from country 0 and need to use technology C that requires a higher marginal cost than dirty technology D to produce the industrial good. However, as $_C > \ _D$, country j's firm is tempted to use technology D without an enforcement mechanism, so law enforcement of country j needs to randomly audit firms to check if the clean technology is being used. Suppose that country j faces the level of enforcement of technology C, $\in [0, 1]$. Then, firm j produces a fraction of its output with technology C and the rest $1 -$ is produced with technology D to save money. Enforcing the use of technology C is costly for the government of country j as it requires strong infrastructure, such as an audit system, and well-disciplined police. Let $F_j(\ )$ be country j's cost of establishing law enforcement that achieves enforcement level $\in [0, 1]$. We assume that $F_j(\ ) = F + f_j(\ )$ with $F \geq 0$, $f_j(0) = 0$, $f_j'(\ ) > 0$, and $f_j''(\ ) > 0$, and that southern countries can differ in their enforcement costs and can be ordered (country 1 is the most efficient in law enforcement).

(A4) Ordered Enforcement Cost: for $\in [0, 1]$, $f_1(\ ) \leq f_2(\ ) \leq \ldots \leq f_m(\ )$ and $f_1'(\ ) \leq f_2'(\ ) \leq \ldots \leq f_m'(\ )$.

A special case of the above is that all southern countries have the same enforcement costs: $f(\ ) = f_j(\ )$ for any $j = 1, \ldots, S$ and any $\in [0, 1]$. Knowing the southern countries' enforcement costs, northern country 0 chooses southern FTA members and sets up an enforcement level standard $\in [0, 1]$, offering them a sign-up subsidy ≥ 0 for joining the FTAs.

2.3 Northern market

The industrial good market in northern country 0 is a Cournot oligopoly with an inverse demand function $P = P(Q)$. Firms in different countries have different effective marginal costs. Northern firm 0 has marginal cost c_0, firm $j \in A$ has marginal cost $c_j = c_C$ or c_D, depending on the type of technology j uses. And firm $j \in S \setminus A$ has marginal cost $c_j = c_D + $. When there are m southern countries that supply the product to country 0, and they have heterogeneous costs $(c_0; c_1 ; \ldots ; c_m)$. Country j's best response is a solution of

$$\arg\max_{Q_j} P\left(Q_j + Q_{-j}\right) Q_j - c_j Q_j; \tag{1}$$

where $Q_{-j} = \sum_{i \neq j} Q_i$. Summing up the first order conditions over $j = 0; 1; \ldots ; m$, we obtain

$$(m + 1) P\left(Q\right) - \sum_{i=0}^{m} c_i + P'\left(Q\right) Q = 0; \tag{2}$$

which determines equilibrium total output Q. We assume:

(A5) Northern country's demand satisfies strategic substitute condition: $P'(Q) + P''(Q)Q_j \le 0$ for all Q and $Q_j < Q$.

2.4 Southern markets

In contrast, we greatly simplify each southern country's market equilibrium. Let country j's domestic inverse demand function be $p(q_j)$. Firm j uses the dirty technology D:

$$_j(q_j) = p(q_j)q_j \quad c_j q_j : \tag{5}$$

If …rm j uses dirty technology, …rm j's monopoly output and pro…t with dirty technology D by q_D and $\ _D = \frac{(p(q_D) - c_D)^2}{-p^0(q_D)}$, where q_D is implicitly de…ned by $p(q_D) \quad c_D + p'(q_D)q_D = 0$. Similarly, with marginal cost c_C, southern countries' monopoly output and pro…t with clean technology C by q_C (de…ned in the same way as q_D) and $\ _C = \frac{(p(q_C) - c_C)^2}{-p^0(q_C)}$. As $c_D < c_C$, $q_C < q_D$ and $\ _C < \ _D$ hold.

If country j is a nonmember of an FTA (j 2 SnA), …rm j uses surely technology D. If country j is a member of the FTA, we can have several di¤erent possible scenarios for the output of …rm j as country j has a clean technology enforcement level .

(A6) Southern FTA member j's industrial good production is capped with $Q_C + q_C$, and the average marginal cost under is $c_C + (1 \quad)c_D$.

This assumption that "j's industrial good production is capped with $Q_C + q_C$" is justi…ed if the law enforcement enforces and monitors …rm j's output level.[12] If …rm j produces more than $Q_C + q_C$, law enforcement proves that …rm j uses dirty technology D, since $c_C > c_D$. Still, …rm j has an incentive to use dirty technology D to produce $Q_C + q_C$ to earn the di¤erence in the marginal costs. Based on enforcement level , …rm j produces $(1 \quad)q_C$ with dirty technology D, and the rest with clean technology C. This assumption implies that each country's

Under this assumption, …rm j earns exporting and domestic pro…ts with the clean technology, and some additional pro…t with the dirty technology $(1 \quad)(c_C \quad c_D)(Q_C + q_C)$ due to limited enforcement.

2.5 Externalities from pollution

The total amount of pollutive emissions in the world is described as follows

$$E = e_C Q_0 + \underset{j\in A}{}\left(e_C + (1 \quad)e_D\right)(Q_j + q_j) + \underset{j\in S\backslash A}{} e_D (Q_D + q_D) ; \qquad (6)$$

where $e_C + (1 \quad)e_D$ is the emission rate of country j for j 2 A, and $Q \quad (Q_0; ::::; Q_m)$ and $q \quad (q_1; ::::; q_m)$ 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. For simplicity, we assume that only the northern country cares about these negative externalities:

(A7) Marginal disutility from negative externalities E from pollutive emissions is $d_N > 0$ in northern country, where it is $d_S = 0$ in southern countries.

Even if $d_S > 0$, the qualitative results of this study will not be a¤ected as long as $d_N > d_S$. However, positive d_S

northern country's consumer surplus is described by $CS(k) = \int_0^{Q(k)} \left(P(Q) - P(Q(k))\right) dQ$. 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 $Q_j(k) \equiv Q_j(Q(k))$ and $\pi_j(k) \equiv \pi_j(Q(k))$ 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 $j \notin A$. The southern countries' domestic supply vector is simply determined as $q_j = q_C$ if $j \in A$, and $q_j = q_D$ otherwise.

The worldwide emission of pollutive substance under this free trade agreement is described by

$$
\begin{aligned}
E(k;\theta) &= e_C Q_0(k) + \sum_{j \in A} (\theta e_C + (1-\theta) e_D)(Q_j(k) + q_C) + \sum_{j \in S \setminus A} e_D (Q_j(k) + q_D) \\
&= e_C Q_0(k) + k(\theta e_C + (1-\theta) e_D)(Q_C(k) + q_C) + (m-k) e_D (Q_D(k) + q_D): \qquad (7)
\end{aligned}
$$

The northern country sets a clean-technology enforcement level $\theta \in [0; 1]$ and a sign-up subsidy $s \geq 0$ for its FTA member (southern) countries, and the northern country agrees to form a free trade agreement with southern country j if country j is willing to adopt the clean technology by spending enforcement cost $F_j(\theta) \geq 0$ (open membership, or non-discrimination). The northern country's social welfare can be written as

$$
SW(k;\theta;s) = \overline{SW}(k) - k s - d_N E(k;\theta); \qquad (8)
$$

where $\overline{SW}(k) = CS(k) + \pi_0(k) + \tau(m-k) Q_D(k)$ is the northern country's gross social welfare—the sum of consumer surplus, producer surplus, and the tariff revenue.

Southern country j' 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 $j \in A$. As we assume $d_S = 0$, the southern countries' gross social welfare excluding the enforcement cost and the sign-up subsidy for the

FTA can be written as

$$sw^{OUT}(k; \ ) \quad cs_D(k) + \ _D(k) + \ _D \tag{9}$$

if $j \in A$, and

$$sw^{IN}(k; \ ) \quad cs_C(k) + \ _C(k) + \ _C$$

Donsimoni et al. (1986), we can show that there always exists a stable FTA.

Proposition 1. For all 2 [0; 1] and all 0, there exists a stable FTA for southern countries under (A1)-(A7).

to find the optimal FTA policy for the northern country, we can use the following two-step procedure: first, for each $k = 1; \ldots; m$, find an optimal combination of policies $({}^k; \ {}^k)$, then solve the optimal FTA size k.

memberships for southern countries k^*:

$$k^* = \arg\max_{k=0;1;\ldots;m} SW(k; \ ^{k*}; \ ^{k*}): \qquad (17)$$

Proposition 2. Suppose that (A1)-(A4), (A5'), (A6), and (A7) hold. Then, the optimal sta-

Proposition 3. Suppose that (A1)-(A4), (A5'), (A6), and (A7) hold. If (i) there are positive joint gains from forming an FTA between the northern country and southern country 1 ($\overline{SW}(1) - d_N E(1;1) + sw^{IN}(1;1) - (F + f_1(1)) > \overline{SW}(0) - d_N E(0;0) + sw^{OUT}(0;0)$), and (ii) the northern country's gains from the emission reduction from forming the FTA exceeds its loss in the gross total surplus ($\overline{SW}(1) - d_N E(1;1) > \overline{SW}(0) - d_N E(0;0)$), then the optimal FTA for the northern country is nontrivial.

Condition (ii) may seem restrictive since it is likely that $\overline{SW}(1) < \overline{SW}(0)$ holds especially if τ is close to the optimal tariff rate for no FTA case. However, it is not difficult to show that condition (ii) holds, if (a) e_C is significantly smaller than e_D, and (b) the northern country has a sufficiently high concern about environmental damages (d_N is significantly high). This can be seen by rewriting the reduction in the emissions by the above FTA:

$$|\Delta E| = E(0;0) - E(1;1)$$
$$= e_C$$

we demonstrate the quantitative properties of our model. In particular, we are interested in how the law enforcement level , the sign-up transfer to the southern member countries, and total emissions of environmental pollutants E are a¤ected by the number of southern member countries in an FTA. We specify the f_k function as follows:

$$f_k(\ ) = f(\ ) = \frac{1}{2}\ ^2; \tag{19}$$

for all $k = 1; :::; m$. This formulation satis…es $f'(0) = 0$ while $f(1) = \quad < 1$. Then, $^*_k$ is written as

$$^*_k = \frac{(e_D \quad e_C)}{} \ '(d_N + d_S) \quad \frac{1 + c_0 + kc_C + (m \quad k)(c_D + \quad) \quad (m+2)\, c_C}{m+2} + \frac{a \quad c_C}{2b}$$

(k C

(and) to increase southern countries' membership by evaluating CS, $_0$, and TR (tari¤ revenues), in addition to emissions E. Here, k = 4 is the optimal number of southern countries in the FTA (Table 1).

(5) Under some parameter values, nonmember southern countries can be e¤ectively excluded from the northern market (if $P(k) < c_C +$).

Moreover, we can easily see how changes in enforcement cost , tari¤ rate , cost of the clean technology c_C, and emissions from the dirty technology e_D; a¤ect the optimal number of southern countries participating in the FTA. In Appendix 3, we show the results of the changes in these values ($_k$ = from 0.02 to 0.03, from 0.1333 to 0.1, c_C from 0.08 to 0.06, and e_D from 0.3 to 0.5), from which we can observe the following.

(1) If the enforcement e¢ ciency is lower (higher), enforcement of clean technology implementation is more di¢ cult and FTA membership declines. This is because to support the southern FTA members becomes more costly. (Table 3)

(2) A lower tari¤ rate ( ) decreases the number of member countries. Southern countries have less incentive to become a member with lower tari¤ rate, since they can still have access to the northern market even if they are outsiders. (Table 4)

(3) If clean technology is less costly (lower c_C), more states will join the FTA. Additionally, the total emission declines because such a reduction will be easier. As c_C goes down, it becomes easier to enforce clean technology, which in turn gives the northern country stronger incentives to accept more southern countries. As a result, both e¤ects bring down the total emissionsns(n)-361(b)14(s)11are 4)

total emissions under the stable FTA in Table 1 is 0.38 whereas the ones under the stable FTA in Table 6 is 0.3762 due to expanded southern membership. (Tables 1 and 6)

The above numerical example implies that the optimal size of the FTA for the northern country cannot be large so that the southern member countries are su¢ ciently motivated to introduce strict environmental regulations. Brandi et al. (2020) investigated the e¤ects of environmental provisions on exports from developing countries based on the newly created dataset on a broad range of environmental provisions across 680 FTAs. Their analysis shows that only developing countries with stricter enforcement of environmental policies can green their exports in response to environmental provisions in trade agreements. Thus, if many participating countries have a low level of enforcement of environmental regulations, they may not necessarily contribute to emission reductions even under trade agreements with environmental provisions.

6 Conclusion

In this paper, we analyzed the stable free trade agreements with environmental provisions between northern and southern countries, explicitly considering clean technology transfers and the enforcement of tighter environmental regulation. We characterized the optimal stable FTA for the northern country, and provided su¢ cient conditions for the optimal stable FTA to be nontrivial. Our numerical results indicated that the optimal size of the FTA for the northern country could be rather small to assure the southern member countries su¢ cient bene…ts of getting access to the lucrative northern market so that they are willing to implement strict environmental measures. It should be noted that behind this result is Proposition 2:

mnalysz-(i)6(o)11(g)-316(t)15(T)96(A)-1(s)-388(w)15(s)6(t)9(h)-3035envirn.ental proviitns.,-3145we s

environmental regulations in southern countries. As several empirical studies examine the

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Appendix 1: Proofs

Proof of Proposition 1. First, note $f_1(\ )\quad f_2(\ )\quad ::: \quad f_m(\ )$ for all $\ 2\ [0;1]$ by (A4).

We will prove that there is a stable FTA by an induction argument.

1. Start with $k = 0$. If $sw^{IN}(1;\ )\quad F\quad f_1(\ ) + \quad sw^{OUT}(0;\ )$, then, $k = 0$ is a stable FTA, and we are done. Otherwise, we have $sw^{IN}(1;\ )\quad F\quad f_1(\ ) + \ > sw^{OUT}(0;\ )$.

2. For an FTA size $k\quad 1$, suppose that $sw^{IN}(k;\ )\quad F\quad f_k(\ ) + \ > sw^{OUT}(k\quad 1;\ )$ holds. This implies $sw^{IN}(k;\ )\quad F\quad f_j(\ ) + \ > sw^{OUT}(k\quad 1;\ )$ for all $j\ 2\ A$. If $sw^{IN}(k+1;\ )\quad F\quad f_{k+1}(\ ) + \quad sw^{OUT}(k;\ )$, then $sw^{IN}(k+1;\ )\quad F\quad f_j(\ ) + \quad sw^{OUT}(k;\ )$ holds for all $j\ 2\ A$, and $A = f1;:::;kg$ is a stable FTA. Otherwise, we have $sw^{IN}(k+1;\ )\quad F\quad f_{k+1}(\ ) + \ > sw^{OUT}(k;\ )$, and the induction hypothesis holds for an FTA size $k + 1$.

3. By induction, $sw^{IN}(m;\ )\quad F\quad f_m(\ ) + \ > sw^{OUT}(m\quad 1;\ )$ holds. This implies that $A = S$ is internally stable. As there are no more southern countries, we conclude that $A = S$ is a stable FTA.

We completed the proof. Q.E.D.

Proof of Lemma 1. First, note that given k and $\ $, the northern country's social welfare $SW(k;\ ;\ )$ is monotonically decreasing in $\ $. Thus, as long as the constraints in (14) are satis…ed, $\ $ should be minimized. In the following, we show that if the …rst constraint is satis…ed with equality then the second condition is also satis…ed. From the above calculations, we know

$$
\begin{aligned}
sw^{IN}(k) &= \quad _C(k) + cs_C + \quad _C + (1 \quad)(q_C + Q_C(k))(c_C \quad c_D) \\
&= \left(\frac{1}{m+2}\right)^2 [1 + c_0 \quad (m+2)c_C + m(c_D + \quad) \quad k(c_D + \quad c_C)]^2 + \frac{3(a \quad c_C)^2}{8b} \\
&+ (1 \quad) \left(\frac{a \quad c_C}{2b} + \frac{1 + c_0 \quad (m+2)c_C + m(c_D + \quad) \quad k(c_D + \quad c_C)}{m+2}\right)(c_C \quad c_D);
\end{aligned} \tag{21}
$$

and

$$
Q_C(k) = \frac{1 + c_0 \quad (m \quad k + 2)c_C + (m \quad k)(c_D + \quad)}{m+2}; \tag{22}
$$

$$
\begin{aligned}
sw^{OUT}(k \quad 1) &= \quad _D(k) + cs_D + \quad _D \\
&= \left(\frac{1}{m+2}\right)^2 [1 + c_0 \quad 2(c_D + \quad) + (c_D + \quad c_C) \quad k(c_D + \quad c_C)]^2 \\
&+ \frac{3(a \quad c_D)^2}{8b} [1 + c_0 \quad 2c_C + m(c_D + \quad c_C) \quad (c_D + \quad c_C)]^2 \\
&\quad [1 + c_0 \quad 2(c_D + \quad) + (c_D + \quad c_C)]^2 :
\end{aligned} \tag{23}
$$

Thus, subtracting the former from the latter, we have

$$
\begin{aligned}
& sw^{OUT}(k \quad 1) \quad sw^{IN}(k) \\
&= \frac{(m+1)(c_D + \quad c_C)[2(1 + c_0) \quad (m+2)c_C + (m+2)(c_D + \quad) \quad 2k(c_D + \quad c_C)]}{(m+2)^2} \\
&\quad (1 \quad) \left(\frac{a \quad c_C}{2b} + \frac{1 + c_0 \quad (m+2)c_C + m(c_D + \quad) \quad k(c_D + \quad c_C)}{m+2}\right)(c_C \quad c_D) \quad D;
\end{aligned} \tag{24}
$$

where $D = \frac{3(a-c_C)^2}{8b} \quad \frac{3(a-c_D)^2}{8b}$. That is, $sw^{OUT}(k \quad 1) \quad sw^{IN}(k)$ is increasing in k and . Because $f_k(\ ) \quad f_{k+1}(\ )$, we conclude that if the first condition holds with equality $sw^{IN}(k;\ ) \quad F \quad f_k(\ ) + \quad = sw^{OUT}(k \quad 1)$, then the second condition holds with slack $sw^{IN}(k+1;\ ) \quad F \quad f_{k+1}(\ ) + \quad < sw^{OUT}(k)$. Q.E.D.

Proof of Proposition 2. The …rst statement follows from Lemma 1. Problem (14) can be written as

$$SW(k;\ ;\ (k;\ )) = CS(k) + \ _0(k) + \ (m \ \ k)\,Q_D(k) \ \ k\ \ (k;\ ) \ \ d_N E(k;\ ): \qquad (25)$$

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

$$k\frac{@}{@} + d_N\frac{@E}{@} = 0: \qquad (26)$$

Rewriting this, we obtain

$$f_k'(\ ^*_k) = d_N\,(e_D \ \ e_C)\ ^{'}1 + c_0 + kc_C + (m \ \ k)\,(c_D + \ \ )$$

written as

$$Q_0(k) = \frac{1}{m+2}\{1 + (kc_C + (m - k)(c_D + \tau)) - (m+1)c_0\}; \tag{33}$$

$$Q_C(k) = \frac{1}{m+2}[1 + c_0 - (m - k + 2)c_C + (m - k)(c_D + \tau)]; \tag{34}$$

$$Q_D(k) = \frac{1}{m+2}[1 + c_0 + kc_C - (k+2)(c_D + \tau)]; \tag{35}$$

respectively. Thus, the equilibrium total output in the northern market is

$$Q(k) = \sum_{i=0}^{m} Q_i(k) = \frac{(m+1) - (c_0 + kc_C + (m-k)(c_D + \tau))}{m+2}. \tag{36}$$

Since $\pi_j = Q_j^2$, profits from the northern market earned by firms in the northern country, the southern FTA country (with the clean technology), and the southern non-FTA country (with the dirty technology) are

$$\pi_0(k) = \left(\frac{1}{m+2}\right)^2 [1 - (m+1)c_0 + kc_C + (m-k)(c_D + \tau)]^2; \tag{37}$$

$$\pi_C(k) = \left(\frac{1}{m+2}\right)^2 [1 + c_0 - (m - k + 2)c_C + (m-k)(c_D + \tau)]^2; \tag{38}$$

$$\pi_D(k) = \left(\frac{1}{m+2}\right)^2 [1 + c_0 + kc_C - (k+2)(c_D + \tau)]^2; \tag{39}$$

respectively. Thus, the northern country's equilibrium consumer surplus CS is calculated as

$$CS(k) = \frac{[(m+1) - (c_0 + kc_C + (m-k)(c_D + \tau))]^2}{2(m+2)^2}. \tag{40}$$

The amount of equilibrium total emissions is written as

$$
\begin{aligned}
E(k; \ ) = {} & (2e_D \quad e_C) \left(\frac{m+1}{m+2} \quad \frac{c_0 + kc_C + (m \quad k)(c_D + \quad)}{m+2} \right) \\
& (e_D \quad e_C)(1 \quad c_C) + e_D \quad k\frac{a \quad c_C}{2b} + (m \quad k)\frac{a \quad c_D}{2b} \\
& (e_D \quad e_C) \frac{1 + c_0 + kc_C + (m \quad k)(c_D + \quad) \quad (m+2)c_0}{m+2} \\
& (e_D \quad e_C)k \quad \frac{1 + c_0 + kc_C + (m \quad k)c_D \quad (m+2)c_C}{m+2} + \frac{a \quad c_C}{2b} \quad : \qquad (41)
\end{aligned}
$$

The Northern country's tari¤ revenue is

$$
TR(k) = \quad (m \quad k) \quad Q_D(k) = \frac{m \quad k}{m+2}[1 + c_0 + kc_C \quad (k+2)(c_D + \quad)] \ ; \qquad (42)
$$

and its social welfare without environmental concerns is

$$
\begin{aligned}
SW^G(k) = {} & CS(k) + \quad {}_0(k) + TR(k) \qquad (43) \\
= {} & \frac{[(m+1) \quad (c_0 + kc_C + (m \quad k)(c_D + \quad))]^2}{2(m+2)^2} \\
& + \left(\frac{1}{m+2} \right)^2 [1
\end{aligned}
$$

$$
TR(k) = (m \quad k) \quad Q_D(k) = \ m \quad k
$$

rate is

$$^{*}(k) = 3 + (1 \quad m)\, c_0 + (5k + mk)\, c_C + (m \quad 5k \quad km \quad 4)\, c_D$$

Table 4: Lower Tari¤ Rate: = 0:1

k	0	1	2	3	4	5	6	7	8	9	10
Q	0.78333	0.78917	0.79500	0.80083	0.80667	0.81250	0.81833	0.82417	0.83000	0.83583	0.84167
P	0.21667	0.21083	0.20500	0.19917	0.19333	0.18750	0.18167	0.17583	0.17000	0.16417	0.15833
Q_0	0.11667	0.11083	0.10500	0.09917	0.09333	0.08750	0.08167	0.07583	0.07000	0.06417	0.05833
Q_C	0.13667	0.13083	0.12500	0.11917	0.11333	0.10750	0.10167	0.09583	0.09000	0.08417	0.07833
Q_D	0.06667	0.06083	0.05500	0.04917	0.04333	0.03750	0.03167	0.02583	0.02000	0.01417	0.00833
$_0$	0.01361	0.01228	0.01103	0.00983	0.00871	0.00766	0.00667	0.00575	0.00490	0.00412	0.00340
$_C$	0.01868	0.01712	0.01563	0.01420	0.01284	0.01156	0.01034	0.00918	0.00810	0.00708	0.00614
$_D$	0.00444	0.00370	0.00303	0.00242	0.00188	0.00141	0.00100	0.00067	0.00040	0.00020	0.00007
CS	0.30681	0.31139	0.31601	0.32067	0.32536	0.33008	0.33483	0.33963	0.34445	0.34931	0.35420