Free Trade Agreements with Environmental Standards

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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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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

participants increases (Proposition 2).

With Proposition 2, it is easy to see that there is a tradeo between having more Southern countries in the FTA and the level of enforcement, but there are other tradeo s as well. With more Southern memberships, a Northern country's consumer surplus increases, while its domestic rm's pro t and its tari revenue decrease. We also do not know how the total amount of emissions would be a ected 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 con rm 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 e ect 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 $S = \{1, \dots, m\}$. The Northern country (denoted by 0) has an inverse demand fui0) inverse

a ects 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 S.

This means that when Northern country 0 and country j 2 S form an FTA, country j must adopt clean technology C that requires $_C$ units of labor, and enforce the usage of the clean technology at least to some extent by spending a xed cost to establish law enforcement. This is because the dirty technology has a lower marginal cost than the clean technology: $_D <$ $_C$. 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 $_j$ 2 $[0;1]$: country j's rm produces only fraction $_j$ of its output with the clean technology and the rest of its output $(1$ $_j)$ 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 xed cost. Let $F_j(\ )$ be country j's cost of introducing the clean technology together with the cost to establish law enforcement that achieve enforcement level 2 $[0;1]$. We assume $F_j(\ ) = F + f_j(\ )$ with F 0, $f_j(0) = 0$, $f_j^0(\ ) > 0$, and $f_j^{00}(\ ) > 0$. We assume that F_js are ordered by e ciency of enforcement technology: i.e., for any 2 $[0;1]$, $f_1(\ )$ $f_2(\ )$ $:::$ $f_m(\ )$ and $f_1^0(\ )$ $f_2^0(\ )$ $:::$ $f_m^0(\ )$ holds.

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

$$E = e_C Q_0^0$$

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 $c_0 = w_N \; C$, the one in Southern country $j \in A$ has marginal cost $c_j = w_S \; C$ if $j \in A$, and the one in country $j \in S \setminus A$ has marginal cost $c_j = w_S \; D +$ if $j \in S \setminus A$. When there are m countries that supply the product to country i, and they have heterogeneous costs $c_0, (c_1, \ldots, c_m)$, 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

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

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

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

and

$$\pi_j(Q) = \frac{(P(Q) - c_j)^2}{-P'(Q)}; \tag{2}$$

as long as $P(Q) \geq c_j$ 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,

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

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 affects social welfare through the worldwide emission of pollutive substances E and Southern member countries' policy enforcement only.

Let $Q(k)$ be the solution of equation (1) for $c_0 = w_N\gamma_C$, $c_j = w_S\gamma_C$ for all $j \in A$, and $c_j = w_S\gamma_D$ for all $j \notin A$. The Northern country's consumer surplus is described by $CS(k) = \int_0^{Q(k)} \left(P(\tilde{Q}) - P(Q(k))\right) d\tilde{Q}$. Let $\mathbf{Q}(k) \equiv (Q_0(k); Q_1(k); \ldots; Q_m(k))$ and $\pi(k) \equiv (\pi_0(k); \pi_1(k); \ldots; \pi_m(k))$ be such that $Q_j(k) \equiv Q_j(Q(k))$ and $\pi_j(k) \equiv \pi_j(Q(k))$ for the above $c = (c_0; c_1; \ldots; c_m)$. 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 $\theta \in [0, 1]$ and a sign-up subsidy $\tau \geq 0$ 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 $E_j(\theta) \geq 0$ (open membership, or non-discrimination). The worldwide emission of pollutive substance under this free trade agreement is described by

$$E(k;\theta) = e_C Q_0(k) + \sum_{j \in A} (\theta e_C + (1-\theta)e_D)(Q_j(k) + q_C) + \sum_{j \in S \setminus A} e_D(Q_j(k) + q_D)$$
$$= e_C Q_0 + k(\theta e_C + (1-\theta)e_D)(Q_C + q_C) + (m-k)e_D(Q_D + q_D).$$

---

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

The Northern country's social welfare can be written as

$$SW(k; ;) = CS(k) + {}_0(k) \quad k \quad d_N E(k;):$$

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

$$sw^{OUT}(k;) = sw(k;) \quad cs_D + {}_D(k) + {}_D \quad d_S E(k;) \tag{5}$$

if $j \notin A$, and

$$\begin{aligned} sw^{IN}(k;) = sw(k;) \quad cs_C + {}_C(k) + {}_C + \quad F( ) \\ + (1 \quad)({}_C \quad {}_D) w_S (Q_C + q_C) \quad d_S E(k;) \end{aligned} \tag{6}$$

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 $A \subseteq S$ 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 $c_j = w_S \; {}_C$ and countries j in $S \backslash A$ have marginal costs $c_j = w_S \; {}_D + \;$. The equilibrium set A of the Southern FTA member countries k is described by the following two inequalities:

$$sw^{IN}(k;) \quad F \quad f_j( ) + \quad sw^{OUT}(k \quad 1;) \text{ for all } j \in A \text{ (internal stability)}$$

and

$$sw^{IN}(k+1;) \quad F \quad f_j( ) + \quad sw^{OUT}(k;) \text{ for all } j \notin A \text{ (external stability).}$$

If a set of Southern country members satis es both internal and external stability conditions then it is called a stable FTA. E7l013Tf FTe FTpr-27(ci)-304-27i 108.36569701 Tf 74=(hpremo)-303(.

Proof. First note $f_1( ) \quad f_2( ) \quad ::: \quad f_m( )$ for all $\quad 2 \ [0;1]$ by assumption. Thus, if $sw^{IN}(k;) \quad F \quad f_k( ) + \quad sw^{OUT}(k \quad 1;)$ holds then $sw^{IN}(k;) \quad F \quad f_{k^0}( ) + \quad sw^{OUT}(k \quad 1;)$ holds for all $k^0 \quad k$. And if $sw^{IN}(k+1;) \quad F \quad f_k( ) + \quad sw^{OUT}(k;)$ holds then $sw^{IN}(k+1;) \quad F \quad f_{k^0}( ) + \quad sw^{OUT}(k;)$ for all $k^0 \quad k$.

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 $sw^{IN}(1;) \quad F \quad f_1( ) + \quad sw^{OUT}(0;)$, then $k = 0$ is a stable FTA. Since there is no stable FTA, we have $sw^{IN}(1;) \quad F \quad f_1( ) + \quad sw^{OUT}(0;)$.

2. For $k \quad 1$, suppose that $sw^{IN}(k^0;) \quad F \quad f_{k^0}( ) + \quad > sw^{OUT}(k^0 \quad 1;)$ holds for all $k^0 \quad k$. This implies $sw^{IN}(k;) \quad F \quad f_k( ) + \quad > sw^{OUT}(k \quad 1;)$. If $sw^{IN}(k + 1;)$

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

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

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

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

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

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

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

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

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

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

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 $q_D = \frac{a-c_D}{2b}$, $\pi_D = \frac{(a-c_D)^2}{4b}$,

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

$$E(k;\ \ ) = (2\,e$$

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

$$
\begin{aligned}
(k;\ ) = {} & \frac{3(a \quad c_C)^2}{8b} + \frac{3(a \quad c_D)^2}{8b} + F + f_k(\ ) \\
& \frac{1}{m+2}\ ^2 (m \quad 1)(\ c_C + (c_D + \ )) \\
& f\ 2(1 + c_0) \quad (m \quad 2k + 3)\, c_C + (m \quad 2k \quad 1)(c_D + \ ) g \\
& + d_S \ (3e_D \quad 2e_C) \ \frac{c_C + (c_D + \ )}{m+2} \quad e_D \quad \frac{a \quad c_C}{2b} + \frac{a \quad c_D}{2b} \\
& (e_D \quad e_C) \quad \frac{1 + c_0 + kc_C + (m \quad k)(c_D + \ ) \quad (m+2)\, c_C}{m+2} + \frac{a \quad c_C}{2b} \\
& + (e_D \quad e_C)(k \quad 1) \quad \frac{c_C + (c_D + \ )}{m+2}
\end{aligned}
$$

This implies $\frac{@}{@k} > 0$ 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 $1 \quad _1 \quad _2 \quad ::: \quad _m \quad 0$ with strict inequalities $_{k \ 1} > \ _k > \ _{k+1}$ for all ks with an interior solution $1 > \ _k > 0$.

Proof. Problem (8) can be written as

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

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

$$k \frac{@}{@} + d_N \frac{@E}{@} = 0:$$

Rewriting this, we obtain

$$
\begin{aligned}
f_k^0(\ _k) = (e_D \quad e_C)\ (d_N + d_S) \ & \frac{1 + c_0 + kc_C + (m \quad k)(c_D + \ ) \quad (m+2)\, c_C}{m+2} + \frac{a \quad c_C}{2b} \\
& (k \quad 1)\, d_S \quad \frac{c_C + (c_D + \ )}{m+2}
\end{aligned}
$$

Since $(c_D + \ ) > c_C$, the RHS is decreasing in k. Since $f_k^{00}(\ ) > 0$ and $f_k^0(\ ) \quad f_{k \ 1}^0(\ )$ for all , we conclude $_k < \ _{k \ 1}$ holds for all k as long as they are interior solutions.

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

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	

become a member to avoid the considerably high tari 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.

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 a ect 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: $P(Q) = 1 \quad Q$. Firm j's pro t maximization problem is

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

The rst order condition is

$$1 \quad \sum_{i=0}^{m} Q_i \quad Q_j \quad c_j = 0:$$

Summing them up, we obtain

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

and

$$Q = \sum_{i=0}^{m} Q_i = \frac{m+1}{m+2} \quad \frac{1}{m+2} \sum_{i=0}^{m} c_i :$$

Let $_C w_N = c_0$, $_C w_S = c_C$, and $_D w_S = c_D$. We assume that in the presence of a tari 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 $c^{OUT} = c_D + \quad > c^{IN} = c_C$ naturally although $c_C > c_D$ holds. The equilibrium output by country j when k Southern countries participate in the FTA is

$$\begin{aligned} Q_j &= \frac{1}{m+2} + \frac{1}{m+2} \sum_{i=0}^{m} c_i \quad c_j \\ &= \frac{1}{m+2} \{ 1 + (c_0 + k c_C + (m \quad k)(c_D + \quad)) \quad (m+2) c_j \} : \end{aligned}$$

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

$$Q_0(k) = \frac{1}{m+2} \{ 1 + (k c_C + (m \quad k)(c_D + \quad)) \quad (m+1) c_0 \} ;$$

$$Q_C(k) = \frac{1}{\quad}$$

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

$$_C(k) = \frac{1}{m+2}^2 [1 + c_0 \quad (m \quad k + 2)\, c_C + (m \quad k)(c_D + \quad)]^2 ;$$

$$_D(k) = \frac{1}{m+2}^2 [1 + c_0 + kc_C \quad (k + 2)(c_D k$$

with clean technology in the Northern market. The fourth term represents an indirect e ect 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 di erent cases: being a member or a nonmember of the FTA. Southern countries' social welfare can be written as

$$sw^{OUT}(k; \ ) = cs_D + \ _D(k) + \ _D \quad d_S E(k; \ )$$
$$= \frac{(a \quad c_D)^2}{8b} + \quad \frac{1}{m+2} \ ^2 [1 + c_0 + kc_C \quad (k+2)(c_D + \quad)]^2 + \frac{(a \quad c_D)^2}{4b}$$
$$d_S E(k; \ )$$

if $j \not\supseteq A$, and

$$sw^{IN}(k; \ ) = cs_C + \ _C(k) + \ _C + (1 \quad)(\ _C \quad \ _D) w_S (Q_C + q_C) \quad d_S E(k; \ )$$
$$= \frac{(a \quad c_C)\, b}{}$$

sign-up subsidy 0 to the participants of FTA from Southern countries. In order to nd the optimal FTA policy for the Northern country, we can use the following procedure. First for each $k = 1; :::; m$, nd an optimal combination of policies $({}^k; {}^k)$ by solving the problem:

$$({}^k; {}^k) \; 2 \; \arg\max_{;} SW(k; ;) \quad s:t: \quad sw^{IN}(k;) \quad F \quad f_k( ) + \quad sw^{OUT}(k \quad 1;):$$

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

$$\begin{aligned} &= s(; k) \\ &= \quad sw^{IN}(k;) + F(0) + f( ) + sw^{OUT}(k \quad 1;) \\ &= \frac{3(2a \quad c_C \quad c_D)(c_C \quad c_D)}{8b} \\ &\quad (1 \quad)(c_C \quad c_D) \quad \frac{1 + c_0 \quad (m \quad k+2)\, c_C + (m \quad k)(c_D + \quad)}{m+2} + \frac{a \quad c_C}{2b} \\ &\quad d_S \quad \frac{1}{m+2}^{2} (m \quad 1)(c_D + \quad c_C) \quad f \; 2(1 + c_0) + (m \quad 2k+1)(c_D + \quad c_C) g \\ &+ F + f_k( ) + d_S E(k;): \end{aligned}$$

Problem (8) can be written as

$$SW(k; ; (k;)) = CS(k) + {}_0(k) + (m \quad k)\, Q_D(k) \quad k \; (k;) \quad d_N E(k;):$$

Thus, given k, the social optimum ${}_k$ is characterized by

$$k \frac{@}{@} + d_N \frac{@E}{@} = 0:$$

Thus, we have

$$\begin{aligned} &k f_k^0({}_k) \quad d_S (e_D \quad e_C)\, k \quad \frac{1 + c_0 + k c_C + (m \quad k)(c_D + \quad) \quad (m+2)\, c_C}{m+2} + \frac{a \quad c_C}{2b} \\ &+ d_S (e_D \quad e_C)\, k (k \quad 1) \quad \frac{c_C + (c_D + \quad)}{m+2} \\ &\quad d_N (e_D \quad e_C)\, k \quad \frac{1 + c_0 + k c_C + (m \quad k)(c_D + \quad) \quad (m+2)\, c_C}{m+2} + \frac{a \quad c_C}{2b} \\ &= 0: \end{aligned}$$

Rewriting this, we obtain

$$f_k^0(\;\;_k) = (\;e_D \quad e_C)\;\;(d_N + d_S)\;\;\frac{1 + c_0 + kc_C + (\;m \quad k)(c_D + \quad) \quad (m+2)\;c_C}{m+2} + \frac{a \quad c_C}{2b}$$

$$(k \quad 1)\,d_S \quad \frac{c_C + (\;c_D + \quad)}{m+2} \quad :$$

Since $(c_D + \quad) > c_C$, the RHS is decreasing in k. Since $f_k^{00}(\;\;) > 0$ and $f_k^0(\;\;) \quad f_{k\;1}^0($

Table A2: Higher Tari Rate: = 0:15

k	0	1	2	3	4	5	6	7	8	9	10
Q	0.64583	0.65417	0.6625	0.67083	0.67917	0.6875					

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

k	0

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