FDI and Environmental Standard: Pollution Haven or Race to the Bottom?

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Abstract

This paper theoretically examines the relationship between FDI and environmental standard regulation. In particular, implications on "Pollution Haven", "Race to the Bottom" and "Regulatory Chill" hypotheses are given. Using a two country reciprocal trade model, we show that instead of "Race to the Bottom", a "Race to the Top" regulatory policy arises in equilibrium for transboundary pollution if markets are small. When markets are relatively large, "Regulatory Chill" occurs. Equilibrium FDI structure with the presence of emission standard regulation is also provided.

Key words: FDI, Pollution Haven, Race to the Bottom, Regulatory Chill, environmental standards

JEL Classification: F12, F18, F23

1 Introduction

The world is witnessing increasing economic and political concerns on environmental problems, for example, various coordinations and collaborations in environment protection and environmental policies have been put into the agenda of many bilateral and multilateral cooperations. This is because environment not only affects the quality of human life, but also, as a kind of endowment and important input factor, is closely related with many economic activities and even economic growth.

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One of the economic activities quite related to environment is international trade. The relationship of these two lies in two dimensions. One dimension is that the liberalization of international trade has impact on the quality of environment. This topic has been widely discussed[1]. However, no consensus, both in empirical and theoretical studies, has been reached on whether freer trade is beneficial or detrimental to environment. The other dimension of the trade-environment relationship is that environment policies have become the strategic instruments of countries to influence international trade. A seminal paper of this approach is Barrett (1994) who adopts a two country reciprocal export model, and finds that countries may impose "weaker" or "stronger" environmental standards to influence their exports, depending on the nature of competition and market structures in their domestic markets.

Foreign direct investment (FDI), a substitute of export, increases rapidly in the recent decades. Sales of foreign affiliates almost double global exports of goods and non-factor services in monetary level in recent years. To some extent means that FDI plays even a more important role in the global economy than export. With very few exceptions[2], there is in lack of papers studying the relationship between FDI and environmental policies, particularly emission standard. The current paper attempts to fill the gap.

The topic of the current paper is closely related with the literature discussing "pollution haven" hypothesis and "race to the bottom" effect. Foot-loose investors of dirty industries seek to locate their investment in countries with laxer environment standard in order to economize their cost of production and gain competitive edge in international market. "Pollution haven" hypothesis postulates that a Southern country (usually accompanied with low environmental standard), lowers its emission standard to successfully attract and host dirty industries[3]. "Race to the bottom" effect refers to the case that to attract FDI inflow and/or keep their own industries at home, all countries strategically reduce their strictness of environment regulations.

Empirical papers give mixed report. One group of papers (Levinson (1996), Letchumanan and Kodoma (2000), and Eskeland and Har-

[1] See Grossman and Krueger (1991), Anderson and Blackhurst (1992), Cole (1999), Copeland and Taylor (1995), Copeland and Taylor (1995), Antweiler, Copeland and Taylor (2001), Beghin et al (1995)

[2] De Santis and Stähler (2008) study FDI and emission tax and find that such tax may not be necessarily low in host country since the host country has an incentive to shift the rent away from the source country, through tax revenues.

[3] Neumayer (2000) defines that a country provides a pollution haven if it sets its environmental standard below the socially efficient level in order to attract foreign investment from higher standards countries.

rison (2003)) find no significant correlation between location of multinational enterprises (MNEs) and environmental standards in host countries. Smarzynska and Wei (2001) identifies some difficulties obstructing researchers in finding empirical evidence to support "pollution haven" hypothesis. However, they also do not find sound support for this hypothesis using a firm level data set on investment project in 24 transition economies. Gray (2002) points out that such a negative relationship may be industry specific, for example, in the furniture industry. Xing and Kolstad (2002) adopt a new measure for strictness of environmental regulation and find that for pollution-intensive industry, lax environment policies do attract foreign investment. Aliyu (2005) concludes that environmental policy is important in explaining the outflow of FDI from OECD countries to less developed countries.

In this paper, we prove that FDI will raise the environmental standard of the host country. Several theoretical papers obtain similar results under different analytical frameworks. Wu (2004) finds that the strategic rent extraction behavior between governments due to asymmetric information between MNEs and government weakens the pollution haven hypothesis. This actually provides a theoretic explanation for the failure of empirical studies in finding evidence supporting pollution haven hypothesis. Using a political economy model with FDI liberalization, Cole *et al.* (2006) find that the environmental tax rate will increase with the number of foreign firms in a country with low degree of corruptibility. Kayalica and Lahiri (2005) discuss the strategic emission standard when FDI is present in a third country market model. They find that when the host country of FDI does not allow free entry of FDI, the emission standard of the host country is stricter. However, FDI deregulation may increase source country's emission standard under some circumstances. Using a market share game on optimal emission tax, De Santis and Stähler (2008) conclude that the liberalization of FDI will drive the host countries of FDI to impose a higher environmental tax rate which is actually Pigouvian tax rate.

The current paper studies FDI and emission standards in a North-South model. The game played is market share game, that is, firms move before governments make policy decisions. Note that the environmental policy instrucment in this model is emission standard which is different from Cole *et al.* (2006) and De Santis and Stähler (2008) whose policy instrucment is environmental tax.

Emission standard, also called "performance standard", is a kind of command and control (CAC) instrument. It does not bring government any fiscal revenue. Environmental tax, which could generate revenue for the government, is a representative kind of market-based incentive

(MBI) instrument. Stavins (2000) points out that incentives (like tax) are more “cost-effective” than CAC restrictions (like emission standard), as they could realize the environmental target with the lowest social cost by efficiently allocating the burden of pollution reduction under asymmetry information. Because of “tax-exemption effect of environmental standard” regulation (Ulph (1998)), emission tends to be higher under standard compared to tax. Kiyono and Okuno-Fujiwara (2003) demonstrate that under open economy scenario countries are worse off by shifting from environment tax to environment standard, as this will increase the production and total emission. Fullerton (2002) has clarified that emission standard and environmental tax can achieve the same efficiency effect, i.e. they can improve the economic efficiency by the same level under symmetric information. Yet emission standard could be more efficient in monitoring and enforcing when information is asymmetric.

The novelty of the model is that it combines countries’ technology asymmetry, endogenous tariffs (i.e.endogenous trade cost), transboundary pollution, and optimal emission standards together. The main results of this paper are that (i) the tariff of North is prohibitive in equilibrium when market sizes of both countries are not large enough, that is, the Southern firm will not be able to sell its product in the Northern market unless it builds a new plant in the North through FDI; (ii) if market sizes of the two countries are small, FDI will raise the emission standard of the host country, which is contrary to the "race to the bottom" effect; if market sizes are larger enough, FDI will not change the emission standard of the South which is in the laxest form, this theoretically supports "regulatory chill"; (iii) Equilibrium FDI is contingent on the fixed cost of FDI, as traditional proximity-concentration tradeoff predicts.

The organization of the rest of the paper is as follows: Section 2 introduces the basic model, Section 3 discusses the equilibria of emssion standards under different FDI-export scenarios of firms, Section 4 studies the FDI equilibrium, Section 5 concludes the model.

2 The Model

There are only two countries in the model, a North and a South. Each country has one firm. Countries differ in production technologies: the North is endowed a cleaner technology, that is, when producing the same amount of product, the firm in the North generates less emissions than does the one in the South. Pollution is completely transboundary, as in the case of greenhouse gas (GHG) emission.

Firms in both countries serve their domestic markets, and at the same time, they could serve the foreign markets through export or FDI (but not both export and FDI). If a firm sells its product to the foreign market through export, it faces an endogenous tariff set by the welfare-maximizing foreign government. This tariff is just the cost of international trade. If the firm serves the foreign market through FDI, it faces a fixed lump sum cost of building up a new plant. Firms' FDI decision is based on proximity-concentration tradeoff.

The game played in this model is market share game in which firms make decisions before governments, instead of race-to-the-bottom game in which governments make decisions on environmental policies first. The order of the play is as follows:

- Stage 1: Firms choose their international market strategy, i.e., export or FDI;
- Stage 2: Given firms' decisions, governments set their welfare-maximzing emission standards;
- Stage 3: Firms decide their emission levels according to the established emission standards;
- Stage 4: Governments set their optimal tariffs, if export is present;
- Stage 5: Firms make production decisions for both the domestic and foreign markets, under Cournot competition, and profits and welfare are realized.

Both countries have simple linear demand $Q_i = a - P_i$, $i \in \{n, s\}$, where n and s stand for the North and South respectively. Q_i and P_i are the total consumption and product price of country i respectively. $Q_i = q_i^i + q_j^i$, $i, j \in \{n, s\}$, $i \neq j$. q_i^i stands for the quantity of firm i sells in its home market, while q_j^i is the quantity of firm $j\,(\neq i)$ sells in its home market, i.e. market i.

In this model, z_i, $i \in \{n, s\}$, stands for the emission standard of country i. Following Kayalica and Lahiri (2005), assume that the marginal cost function of firm i is $c_i\left(e_{ij}\right) = c_{i0} + \mu_i\left(\theta_i - e_{ij}\right)$, $i, j \in \{n, s\}$. It is a function of e_{ij}, which is the emission level chosen by firm i when it produces the goods in country j and is constrained by the emission standard of country j, z_j. Let θ_i be the total amount of pollutant generated by firm i when producing one unit of product (called "pollutant of unit product" in the rest of this paper), then $0 \leq e_{ij} \leq \min\{\theta_i, z_j\}$, and $\theta_i - e_{ij}$ is the amount of abatement. North has a cleaner technology, or $\theta_n < \theta_s$. μ_i is the marginal cost of abatement, and c_{i0} is the part of marginal cost of production independent of emission abatement. To simplify the discussion in the rest of this paper, and without loss of generality, assume that $c_{i0} = 0$, $\mu_i = 1$, i.e, $c_i(e_{ij}) = \theta_i - e_{ij}$, where $\theta_i < a$.

The pollution considered in this model is transboundary, that is, a public bad. The damage function of emission is $D(E) = \omega E$, where E is the total amount of the world emission, and ω describes the seriousness of the environmental problem. Assume in this model that $\omega = 1$.

When firms export their products to the foreign markets, they face tariffs set by the foreign governments. Denote T_i as the tariff of country i to the foreign firm. The fixed cost of building a plant is F.

3 Emission Standard Game

This section discusses the equilibria of emission standard under different FDI-export scenarios. Note that a government will not set an emission standard that is higher than the pollutant of unit product (θ) of every firm producing goods in this country[4]. Secondly, for firm i producing goods in country j, there is $e_{ij} = \min\{\theta_i, z_j\}$. This is due to the nature of this model. In the model of this paper, more emissions incur no cost to the firms, so a profit-maxizing firm will not stop increasing it emission level until it reaches $\min\{\theta_i, z_j\}$.

3.1 No FDI

Consider first the case that both firms from the North and South are not allowed to conduct FDI, so they can only enter foreign markets through export. The objective functions of the firms in South and North are respectively

$$\max_{\{q_s^s, q_s^n\}} \pi_s^{EE} = (a - q_s^s - q_n^s - c_s(e_{ss}))\, q_s^s + (a - q_n^n - q_s^n - c_s(e_{ss}) - T_n)\, q_s^n, \tag{1}$$

$$\max_{\{q_n^n, q_n^s\}} \pi_n^{EE} = (a - q_n^n - q_s^n - c_n(e_{nn}))\, q_n^n + (a - q_s^s - q_n^s - c_n(e_{nn}) - T_s)\, q_n^s. \tag{2}$$

The superscript EE stands for the case that both countries serve foreign market through export. The first parts of both profit functions are the profits of firms obtained in their home market, and the second parts are export profit. Exports q_s^n, q_n^s should be of nonnegative quantities.

For the southern firm, its output levels in domestic and foreign mar-

[4] It is technically infeasible that a firm will choose a emission level beyond its pollutant of unit product, so it is indifferent both for the government and firms to have an emission standard beyond the pollutant of unit product of every firm producing goods in this country and an emission standard equal to the highest pollutant of unit product in this country.

ket are respectively

$$q_s^{s*} = \frac{a - 2c_s(e_{ss}) + c_n(e_{nn}) + T_s}{3}, \tag{3}$$

$$q_s^{n*} = \frac{a - 2c_s(e_{ss}) + c_n(e_{nn}) - 2T_n}{3}. \tag{4}$$

For the northern firm, its production levels in domestic and foreign market are respectively

$$q_n^{n*} = \frac{a - 2c_n(e_{nn}) + c_s(e_{ss}) + T_n}{3}, \tag{5}$$

$$q_n^{s*} = \frac{a - 2c_n(e_{nn}) + c_s(e_{ss}) - 2T_s}{3}. \tag{6}$$

When firms do not conduct FDI, they set their emission levels according to the emission standard of their home countries. In this case the total amount of world emission is $E^{EE} = (q_s^{s*} + q_s^{n*})\, e_{ss} + (q_n^{n*} + q_n^{s*})\, e_{nn}$. The social welfare of the South and North countries under the no-FDI case can be expressed as

$$W_s^{EE} = \frac{Q_s^2}{2} + \pi_s^{EE} + T_s q_n^{s*} - D\left(E^{EE}\right), \tag{7}$$

$$W_n^{EE} = \frac{Q_n^2}{2} + \pi_n^{EE} + T_n q_s^{n*} - D\left(E^{EE}\right). \tag{8}$$

The components of social welfare under this scenario include consumer surplus $\left(\frac{Q_s^2}{2}, \frac{Q_n^2}{2}\right)$, profits, tariff revenue $(T_s q_n^{s*}, T_n q_s^{n*})$, and environmental damage. According to (3), (4), (5), (6), optimal tariffs of the South and North countries can be solved out through FOCs of social welfare maximization, they are

$$T_s^* = \frac{a - c_n(e_{nn}) - e_{ss} + 2e_{nn}}{3}, \tag{9}$$

$$T_n^* = \frac{a - c_s(e_{ss}) - e_{nn} + 2e_{ss}}{3}. \tag{10}$$

Since firms only produce goods in their home country and set emission levels according to domestic emission standards, there must be $e_{ss} = z_s \leq \theta_s$, $e_{nn} = z_n \leq \theta_n$. Substitute (3), (4), (5), (6), (9), (10) into the social welfare functions, i.e. (7), (8), it is easy to find that W_s^{EE} and W_n^{EE} are concave in z_s and z_n respectively. According to the best response functions drived from (7), (8) under constraits $z_s \leq \theta_s$, $z_n \leq \theta_n$, the equilibrium of emission standard should be

$$(z_s^*, z_n^*) = \begin{cases} (a - \theta_n, a - \theta_s), \text{if } \theta_s < a < \theta_s + \theta_n; \\ (\theta_s, \theta_n), \text{if } a \geq \theta_s + \theta_n. \end{cases} \tag{11}$$

This emission standard equilibrium leads to the following proposition.

Proposition 1 *When the market sizes of countries are small, that is, $\theta_s < a \leq 4\theta_s - 2\theta_n$, the tariff of the North is prohibitive and prevent southern firm exporting to the North in equilibrium, i.e. $q_s^{n*} = 0$; when the market sizes of countries are larger enough, that is $a > 4\theta_s - 2\theta_n$, the southern firm exports to the North.*

Proof. Substitute (11) and (9), into (4), the optimal quantity of southern firm's export to the North can be reduced to

$$q_s^{n*} = \frac{a - 4\theta_s + 3\theta_n - z_n^*}{9}.$$

- When $\theta_s < a < \theta_s + \theta_n$, $q_s^{n*} = \frac{-(3\theta_s - 3\theta_n)}{9}$. Since $\theta_s > \theta_n$, $q_s^{n*} < 0$. q_s^{n*} should be a non-negative quantity, so in equilibrium, $q_s^{n*} = 0$;
- When $\theta_s + \theta_n \leq a \leq 4\theta_s - 2\theta_n$, $q_s^{n*} = \frac{a-(4\theta_s - 2\theta_n)}{9} < 0$. q_s^{n*} should be a non-negative quantity, so in equilibrium, $q_s^{n*} = 0$;
- When $a > 4\theta_s - 2\theta_n$, $q_s^{n*} = \frac{a-(4\theta_s - 2\theta_n)}{9} > 0$.

■

Intuitively, when market demand is small, the benefit of environment outweights the loss from consumer surplus. But when markets are large, such relation reverses. According to Proposition 1, because of corner solutions, the outputs should be modified when $\theta_s < a \leq 4\theta_s - 2\theta_n$, that is, $q_s^{n*} = 0$ and $q_n^{n*} = \frac{(a - c_n(e_{nn}))}{2}$(northern firm is monopolist in its domestic market). The equilibrium of emission standard is described below,

$$(z_s^*, z_n^*) = \begin{cases} \left(a + \frac{\theta_n}{2} - \frac{3\theta_s}{2}, a + \theta_n - 2\theta_s\right), \text{if } 2\theta_s - \theta_n < a < 2\theta_s; \\ \left(a + \frac{\theta_n}{2} - \frac{3\theta_s}{2}, \theta_n\right), \text{ if } 2\theta_s \leq a < \frac{5\theta_s}{2} - \frac{\theta_n}{2}; \\ (\theta_s, \theta_n), \text{if } a \geq \frac{5\theta_s}{2} - \frac{\theta_n}{2}. \end{cases} \tag{12}$$

3.2 Unilateral FDI from North to South

This subsection considers the case where the northern firm serves the Southern market through FDI, while southern firm serves the northern market through export (we use superscript FE to label this case). When the northern firm establishes a new plant in the South instead of exporting, it will not suffer from trade cost (the tariff) any more, however, there is a fixed cost of FDI, F. The objective functions of South and North firms under this case are respectively,

$$\underset{\{q_s^s, q_s^n\}}{\text{Max}}\ \pi_s^{FE} = (a - q_s^s - q_n^s - c_s(e_{ss}))\, q_s^s + (a - q_n^n - q_s^n - c_s(e_{ss}) - T_n)\, q_s^n, \tag{13}$$

$$\underset{\{q_n^n, q_n^s\}}{\text{Max}}\, \pi_n^{FE} = (a - q_n^n - q_s^n - c_n(e_{nn}))\, q_n^n + (a - q_s^s - q_n^s - c_n(e_{ns}))\, q_n^s - F. \tag{14}$$

Compared with (2), the profit of northern firm in the South changes from $(a - q_s^s - q_n^s - c_n(e_{nn}) - T_s)\, q_n^s$ to $(a - q_s^s - q_n^s - c_n(e_{ns}))\, q_n^s - F$, the endogenous trade cost $T_s q_n^s$ becomes fixed plant-building cost F.

Notice that the competition in the northern market is the same with that in the case of no FDI. In Appendix A, it is proven that the proposition 1 also holds in this case. Hence when $\theta_s < a \leq 4\theta_s - 2\theta_n$, $q_s^{n*} = 0$, and the northern firm becomes monopolist in its home market, and $q_n^{n*} = \frac{(a - c_n(e_{nn}))}{2}$.

Since the new subsidiary plant of the northern firm is located in the South, the production of this plant must comply the emission standard set by the southern government. As a result, the cost of the northern firm's product sold in the southern market becomes $c_n(e_{ns})$. As discussed at the beginning of this section, there must be $e_{ns} = \min\{\theta_n, z_s\}$. As for e_{ss}, e_{nn}, the emission levels of firms when they produce goods in their home markets, there is still $e_{ss} = z_s \leq \theta_s$, $e_{nn} = z_n \leq \theta_n$. $\theta_n < \theta_s$, so it is entirely possible that the southern government sets an emission standard $z_s \in (\theta_n, \theta_s)$. If so, $e_{ns} = \theta_n$.

The total amount of world emission in this case is $E^{FE} = (q_s^{s*} + q_s^{n*})\, e_{ss} + q_n^{s*} e_{ns} + q_n^{n*} e_{nn}$. The social welfare functions of South and North are respectively

$$W_s^{FE} = \frac{Q_s^2}{2} + \pi_s^{FE} - D\left((q_s^{s*} + q_s^{n*})\, e_{ss} + q_n^{s*} e_{ns} + q_n^{n*} e_{nn}\right), \tag{15}$$

$$W_n^{FE} = \frac{Q_n^2}{2} + \pi_n^{FE} + T_n q_s^{n*} - D\left((q_s^{s*} + q_s^{n*})\, e_{ss} + q_n^{s*} e_{ns} + q_n^{n*} e_{nn}\right). \tag{16}$$

If $z_s \in [\theta_n, \theta_s]$, as discussed above, there will be $e_{ns} = \theta_n$, $e_{ss} = z_s$, $e_{nn} = z_n$. In this case, W_s^{FE} and W_n^{FE} are both concave in z_s, z_n, then the optimal emission standards of countries are

$$(z_s^*, z_n^*) = (\min\{a - \theta_s + \theta_n, \theta_s\}, \min\{a - \theta_n, \theta_n\}). \tag{17}$$

In Section 2, it was assumed that $a > \theta_s$, therefore $a - \theta_s + \theta_n > \theta_n$. Hence $z_s^* = \min\{a - \theta_s + \theta_n, \theta_s\} \in [\theta_n, \theta_s]$.

If $z_s \in [0, \theta_n)$, then $e_{ns} = z_s$, $e_{ss} = z_s$, $e_{nn} = z_n$. In this case the social welfare of both countries are also concave in z_s, z_n. The equilibrium of emissions standards are,

$$(z_s^*, z_n^*) = (0, \min\{a - \theta_n, \theta_n\}). \tag{18}$$

To determine whether the Southern government will set z_s within $[\theta_n, \theta_s]$ or within $[0, \theta_n)$, one needs to compare the values of W_s^{FE} under these two cases,

$$W_s^{FE} \mid_{(z_s^*,z_n^*)=(\min\{a-\theta_s+\theta_n,\theta_s\},\min\{a-\theta_n,\theta_n\})} - W_s^{FE} \mid_{(z_s^*,z_n^*)=(0,\min\{a-\theta_n,\theta_n\})} \tag{19}$$
$$= \begin{cases} \frac{1}{6}a^2 - \frac{1}{3}a\theta_s + \frac{1}{6}\theta_s^2 - \frac{1}{3}\theta_n\theta_s, \text{ if } a < 2\theta_s - \theta_n; \\ \frac{1}{3}a(\theta_s - \theta_n) - \frac{1}{6}\theta_n^2 - \frac{1}{2}\theta_s^2 + \frac{1}{3}\theta_n\theta_s, \text{ if } a \geq 2\theta_s - \theta_n. \end{cases}$$

The comparison result is contingent on the values of parameters.

3.3 Unilateral FDI from South to North

In subsection 3.1 and 3.2, it is proved that if the southern firm chooses to serve the foreign market through export, it may finally export nothing, as the foreign market is small and the South has competitive disadvantage, the profit earned from export may not cover the trade cost. Here we explore whether FDI can be a substitute. The objective functions of southern and northern firms are respectively

$$\underset{\{q_s^s,q_s^n\}}{\text{Max}}\ \pi_s^{EF} = (a - q_s^s - q_n^s - c_s(e_{ss}))\, q_s^s + (a - q_n^n - q_s^n - c_s(e_{sn}))\, q_s^n - F, \tag{20}$$

$$\underset{\{q_n^n,q_n^s\}}{\text{Max}}\ \pi_n^{EF} = (a - q_n^n - q_s^n - c_n(e_{nn}))\, q_n^n + (a - q_s^s - q_n^s - c_n(e_{nn}) - T_s)\, q_n^s. \tag{21}$$

Superscript EF stands for the case that the northern firm exports and the southern firm carries out FDI. The second part of (20), $(a - q_n^n - q_s^n - c_s(e_{sn}))\, q_s^n - F$, is the profit of southern firm earned by FDI. Notice the cost of the southern firm's product sold in the North, it now becomes $c_s(e_{sn})$, because under FDI the southern firm has to comply the emission standard set by the northern regulator.

From (20) and (21), the optimal output levels of the both firms in each market can be solved out, they are

$$q_s^{s*} = \frac{a - 2c_s(e_{ss}) + c_n(e_{nn}) + T_s}{3}, \tag{22}$$

$$q_s^{n*} = \frac{a - 2c_s(e_{sn}) + c_n(e_{nn})}{3}, \tag{23}$$

$$q_n^{n*} = \frac{a - 2c_n(e_{nn}) + c_s(e_{sn})}{3}, \tag{24}$$

$$q_n^{s*} = \frac{a - 2c_n(e_{nn}) + c_s(e_{ss}) - 2T_s}{3}. \tag{25}$$

The total amount of world emission in this case is $E^{EF} = q_s^{s*}e_{ss} + q_s^{n*}e_{sn} + (q_n^{n*} + q_n^{s*})\, e_{nn}$. The functions of social welfare for the South and North are

$$W_s^{EF} = \frac{Q_s^2}{2} + \pi_s^{EF} + T_s q_n^{s*} - D\left(q_s^{s*}e_{ss} + q_s^{n*}e_{sn} + (q_n^{n*} + q_n^{s*})\, e_{nn}\right), \tag{26}$$

$$W_n^{EF} = \frac{Q_n^2}{2} + \pi_n^{EF} - D\left(q_s^{s*}e_{ss} + q_s^{n*}e_{sn} + \left(q_n^{n*} + q_n^{s*}\right)e_{nn}\right). \tag{27}$$

Substituting the optimal quantities (22) and (25) into (26) yields the optimal tariff of South

$$T_s^* = \frac{a - c_n\left(e_{nn}\right) - e_{ss} + 2e_{nn}}{3}. \tag{28}$$

This expression of optimal tariff is structurally similar to (9), however, they may not equal in value, because the change of the southern firm's way of serving foreign market make induce the change of emission standard equilibrium and the emission levels of firms.

In this case, the emission levels of firms can be characterized as $e_{ss} = \min\{\theta_s, z_s\}$, $e_{sn} = \min\{\theta_s, z_n\}$, $e_{nn} = \min\{\theta_n, z_n\}$. Since $\theta_n < \theta_s$, it is possible that the North sets an emission standard $z_n \in (\theta_n, \theta_s)$ to strengthen the competitive advantage of the northern firm.

- If $z_n \in [\theta_n, \theta_s]$, then there will be $e_{ss} = z_s$, $e_{sn} = z_n$, $e_{nn} = \theta_n$. Substitute (22), (23), (24), (25) and (28) into (26), (27), we can find that W_s^{EF} and W_n^{EF} are concave in z_s, z_n respectively. Accoring to the best response functions between z_s, z_n under constraints $0 \leq z_s \leq \theta_s$ and $\theta_n \leq z_n \leq \theta_s$, the equilirium of emission standards is

$$\left(z_s^*, z_n^*\right) = \begin{cases} \left(a + \frac{\theta_n}{2} - \frac{3\theta_s}{2}, \theta_n\right), \text{ if } \frac{3\theta_s}{2} - \frac{\theta_n}{2} < a < \frac{5\theta_s}{2} - \frac{\theta_n}{2}; \\ \left(\theta_s, \theta_n\right), \text{ if } a \geq \frac{5\theta_s}{2} - \frac{\theta_n}{2}. \end{cases} \tag{29}$$

  In this equilibrium, there is always $z_n^* = \theta_n \in [\theta_n, \theta_s]$.

- If $z_n \in [0, \theta_n)$, then there will be $e_{ss} = z_s$, $e_{sn} = z_n$, $e_{nn} = z_n$. Under this circumstances, W_s^{EF} and W_n^{EF} are also concave in z_s, z_n respectively. Accoring to the best response functions between z_s, z_n under constraints $0 \leq z_s \leq \theta_s$ and $0 \leq z_n < \theta_n$, the equilirium of emission standards is

$$\left(z_s^*, z_n^*\right) = \begin{cases} \left(a + \frac{\theta_n}{2} - \frac{3\theta_s}{2}, 0\right), \text{ if } \frac{3\theta_s}{2} - \frac{\theta_n}{2} < a < \frac{5\theta_s}{2} - \frac{\theta_n}{2}; \\ \left(\theta_s, 0\right), \text{ if } a \geq \frac{5\theta_s}{2} - \frac{\theta_n}{2}. \end{cases} \tag{30}$$

  In this equilibrium, there is always $z_n^* = 0 \in [0, \theta_n)$.

Whether the North will choose θ_n or 0 emission standard depends on the values of North's social welfare under the two cases. To carry out comparison, given the interval of a, compute the difference of the social welfare under these two cases

$$\begin{aligned} & W_n^{EF} \mid_{\left(z_s^*, z_n^*\right) = \left(a + \frac{\theta_n}{2} - \frac{3\theta_s}{2}, \theta_n\right)} - W_n^{EF} \mid_{\left(z_s^*, z_n^*\right) = \left(a + \frac{\theta_n}{2} - \frac{3\theta_s}{2}, 0\right)} \\ & = -\frac{\theta_n}{6}\left(\theta_n + \theta_s\right) < 0; \end{aligned} \tag{31}$$

$$W_n^{EF} \mid_{(z_s^*,z_n^*)=(\theta_s,\theta_n)} - W_n^{EF} \mid_{(z_s^*,z_n^*)=(\theta_s,0)} \tag{32}$$
$$= -\frac{\theta_n}{9}\left(a - \theta_s + 2\theta_n\right) < 0.$$

From the results of (31), (32), it is easy to find that the northern regulator always chooses the most stringent emission standard, i.e., $z_n^* = 0$.

3.4 Bilateral FDI

When both firms conduct FDI, tariffs disappear, and each firm faces a fixed cost of building a new subsidiary plant abroad. The objective functions of the firms are then respectively,

$$\underset{\{q_s^s, q_s^n\}}{\text{Max}}\ \pi_s^{FF} = \left(a - q_s^s - q_n^s - c_s\left(e_{ss}\right)\right) q_s^s + \left(a - q_n^n - q_s^n - c_s\left(e_{sn}\right)\right) q_s^n - F, \tag{33}$$

$$\underset{\{q_n^n, q_n^s\}}{\text{Max}}\ \pi_n^{FF} = \left(a - q_n^n - q_s^n - c_n\left(e_{nn}\right)\right) q_n^n + \left(a - q_s^s - q_n^s - c_n\left(e_{ns}\right)\right) q_n^s - F. \tag{34}$$

where superscript FF stands for bilateral FDI. $\left(a - q_n^n - q_s^n - c_s\left(e_{sn}\right)\right) q_s^n - F$ and $\left(a - q_s^s - q_n^s - c_n\left(e_{ns}\right)\right) q_n^s - F$ are the profits of South and North firms earned in foreign markets through FDI. The total emission of the world becomes $E^{FF} = q_s^{s*} e_{ss} + q_s^{n*} e_{sn} + q_n^{n*} e_{nn} + q_n^{s*} e_{ns}$, where q_s^{s*}, q_s^{n*}, q_n^{n*} and q_n^{s*} are the optimal production levels. The social welfare of the South and North countries are respectively

$$W_s^{FF} = \frac{Q_s^2}{2} + \pi_s^{FF} - D\left(q_s^{s*} e_{ss} + q_s^{n*} e_{sn} + q_n^{n*} e_{nn} + q_n^{s*} e_{ns}\right), \tag{35}$$

$$W_n^{FF} = \frac{Q_n^2}{2} + \pi_n^{FF} - D\left(q_s^{s*} e_{ss} + q_s^{n*} e_{sn} + q_n^{n*} e_{nn} + q_n^{s*} e_{ns}\right). \tag{36}$$

Notice that firms' costs of products sold in foreign market has become $c_s\left(e_{sn}\right)$ and $c_n\left(e_{ns}\right)$, that is because after FDI, the new plant operates in the foreign country and is subject to the emission standard of the foreign government. Based on this fact, the emission levels of firms in each market can be characterized as $e_{ss} = z_s \leq \theta_s$, $e_{sn} = z_n \leq \theta_s$, $e_{nn} = \min\{\theta_n, z_n\}$, $e_{ns} = \min\{\theta_n, z_s\}$.

For any country i, $i \in \{n, s\}$, its emission standard could be within $[0, \theta_n)$ or $[\theta_n, \theta_s]$. The emission standard of each country is discussed below separately.

- For the South:

    1. If $z_s \in [\theta_n, \theta_s]$, then there will be $e_{ns} = \theta_n$ and $e_{ss} = z_s$. W_s^{FF} is concave in z_s, so we can solve out z_s^* from $\frac{\partial W_s^{FF}}{\partial z_n} = 0$,

$$z_s^* = \min\left\{a - \theta_s + \theta_n, \theta_s\right\}. \tag{37}$$

$a > \theta_s$, so $a-\theta_s+\theta_n > \theta_n$. Therefore $z_s^* = \min\{a-\theta_s+\theta_n, \theta_s\}$ falls in the interval $[\theta_n, \theta_s]$.

2. If $z_s \in [0, \theta_n)$, then there will be $e_{ns} = e_{ss} = z_s$. In this case, W_s^{FF} is still concave in z_s, so we can also solve out z_s^* from $\frac{\partial W_s^{FF}}{\partial z_n} = 0$,

$$z_s^* = 0. \tag{38}$$

$z_s^* = 0$ falls in the interval $[0, \theta_n)$, so it is acceptable.

The governments are welfare maximizers, so to determine which standard the South will choose, it is needed to compare the social welfare of the country under these standards. When $a < 2\theta_s - \theta_n$, $z_s^* = \min\{a-\theta_s+\theta_n, \theta_s\} = a-\theta_s+\theta_n$, then

$$\begin{aligned} & W_s^{FF} \mid_{z_s^*=a-\theta_s+\theta_n} - W_s^{FF} \mid_{z_s^*=0} \\ & = \frac{1}{6}\left(a^2 - 2\theta_s a - 2\theta_n\theta_s + \theta_s^2\right). \end{aligned}$$

According to this result, the emission standard of South is

$$z_s^* = \begin{cases} 0, \text{ if } \theta_n < \theta_s \leq \left(2+\sqrt{3}\right)\theta_n \text{ or } \theta_s > \left(2+\sqrt{3}\right)\theta_n \text{ and } a \leq \theta_s + \sqrt{2\theta_s\theta_n}; \\ a-\theta_s+\theta_n, \text{ if } \theta_s > \left(2+\sqrt{3}\right)\theta_n \text{ and } \theta_s + \sqrt{2\theta_s\theta_n} < a < 2\theta_s - \theta_n. \end{cases}$$

When $a \geq 2\theta_s - \theta_n$, $z_s^* = \min\{a-\theta_s+\theta_n, \theta_s\} = \theta_s$, then

$$\begin{aligned} & W_s^{FF} \mid_{z_s^*=\theta_s} - W_s^{FF} \mid_{z_s^*=0} \\ & = \frac{1}{3}a\left(\theta_s - \theta_n\right) - \frac{1}{6}\left(3\theta_s^2 + \theta_n^2 - 2\theta_s\theta_n\right). \end{aligned}$$

Based on this difference of welfare, the emission standard of South is

$$z_s^* = \begin{cases} 0, \text{ if } \theta_n < \theta_s \leq \left(2+\sqrt{3}\right)\theta_n \text{ and } 2\theta_s - \theta_n < a < \frac{\left(3\theta_s^2+\theta_n^2-2\theta_s\theta_n\right)}{2(\theta_s-\theta_n)}; \\ \theta_s, \text{ if } \theta_n < \theta_s \leq \left(2+\sqrt{3}\right)\theta_n \text{ and } a \geq \frac{\left(3\theta_s^2+\theta_n^2-2\theta_s\theta_n\right)}{2(\theta_s-\theta_n)}, \text{ or } \theta_s > \left(2+\sqrt{3}\right)\theta_n. \end{cases}$$

- For the North:

1. If $z_n \in [\theta_n, \theta_s]$, then there will be $e_{nn} = \theta_n$ and $e_{sn} = z_n$. W_n^{FF} is concave in z_n, so from $\frac{\partial W_n^{FF}}{\partial z_n} = 0$, we could solve out the optimal emission standard z_n^*, it is

$$z_n^* = \theta_n. \tag{39}$$

$z_n^* = \theta_n$ is within the interval $[\theta_n, \theta_s]$.

2. If $z_s \in [0, \theta_n]$, then there will be $e_{nn} = e_{sn} = z_n$. W_n^{FF} is still concave in z_n in this case, so from $\frac{\partial W_n^{FF}}{\partial z_n} = 0$, we could solve out the optimal emission standard z_n^*, it is

$$z_n^* = \min \left\{ \frac{(\theta_s - \theta_n)}{2}, \theta_n \right\}. \tag{40}$$

Since $\frac{(\theta_s - \theta_n)}{2} > 0$, $z_n^* = \min \left\{ \frac{(\theta_s - \theta_n)}{2}, \theta_n \right\}$ is within the interval of $[0, \theta_n]$.

To determine which standard the North government will choose, it is needed to compare the social welfare of the country under these standards.

When $\theta_s \geq 3\theta_n$, $z_n^* = \min \left\{ \frac{(\theta_s - \theta_n)}{2}, \theta_n \right\} = \theta_n$, so no matter $z_n \in [\theta_n, \theta_s]$ or $z_s \in [0, \theta_n]$, the regulator always sets $z_n^* = \theta_n$.

When $\theta_n < \theta_s < 3\theta_n$, $z_n^* = \min \left\{ \frac{(\theta_s - \theta_n)}{2}, \theta_n \right\} = \frac{(\theta_s - \theta_n)}{2}$,

$$\begin{aligned} & W_n^{FF} \mid_{z_n^* = \theta_n} - W_n^{FF} \mid_{z_n^* = \frac{(\theta_s - \theta_n)}{2}} \\ & = -\frac{1}{12} (\theta_s - 3\theta_n)^2 < 0. \end{aligned}$$

According to this result, the North always sets $z_n^* = \frac{(\theta_s - \theta_n)}{2}$ if $\theta_n < \theta_s < 3\theta_n$.

3.5 FDI's Impact on Emission Standard

Given the states of both firms and a specific set of parameters, it is easy to determine the emission standard equilibrium. However, *ceteris paribus*, it is still not clear how the liberalization of FDI, or say countries' shift from export to FDI, will affect the emission standard equilibrium of the countries, which is a hot topic among economists, politicians and environmentalists. Existing empirical works generally have difficulties in finding hard evidence to support that the liberalization of FDI will force countries' environmental policies to "race to the bottom" and some countries serve as "pollution havens". Some recent papers, including Wu (2004), Cole *et al.* (2006) and De Santis and Stähler (2008), have provided some explanations for this difficulties and/or results contrary to "race to the bottom" effect and "pollution haven" hypothesis. This paper also shows that "race to the top" may arise in equilibrium. However, our results is not one sided, i.e., under some conditions "regulatory chill" also occurs.

In the rest of this subsection, let the combinations of FDI and Ex denote specific FDI-export scenarios. The left term in the parenthesis stands for the strategy of the northern firm, and righ term stands for that of the southern firm, for instance, (FDI, Ex) denotes the case that northern firm conducts FDI and South exports.

Table 1 depicts the equilibria of emission standards under different FDI-export scenarios, when the technological gap between North and South is small and market sizes are small.

Table 1. Equilibria of Emission Standard with $\theta_n<\theta_s<\frac{3}{2}\theta_n$ and $2\theta_s-\theta_n<a<2\theta_n$

$\diagdown$	(Ex, Ex)	(FDI, Ex)	(Ex, FDI)	(FDI, FDI)
z_n^*	$a+\theta_n-2\theta_s$	$a-\theta_n$	0	$\frac{(\theta_s-\theta_n)}{2}$
z_s^*	$a+\frac{\theta_n}{2}-\frac{3\theta_s}{2}$	0	$a+\frac{\theta_n}{2}-\frac{3\theta_s}{2}$	0

In Table 1, observe that under the (Ex, Ex) case, since $\theta_n < \theta_s$, there is $z_n^* = a+\theta_n-2\theta_s < z_s^* = a+\frac{\theta_n}{2}-\frac{3\theta_s}{2}$, which implies that the North sets a more stringent emission standard than the South. Under (FDI, Ex) and (Ex, FDI), the host countries of FDI, i.e., South and North respectively, both set their emission standards at 0, the most stringent form of environmental policy. Table 2 below reports similar results.

Table 2. Equilibria of Emission Standard with $\theta_n<\theta_s<\frac{3}{2}\theta_n$ and $4\theta_s-2\theta_n<a<\frac{\left(3\theta_s^2+\theta_n^2-2\theta_s\theta_n\right)}{2(\theta_s-\theta_n)}$

$\diagdown$	(Ex, Ex)	(FDI, Ex)	(Ex, FDI)	(FDI, FDI)
z_n^*	θ_n	θ_n	0	$\frac{(\theta_s-\theta_n)}{2}$
z_s^*	θ_s	0	θ_s	0

In table 2, under (Ex, Ex), since $z_n^* = \theta_n < z_s^* = \theta_s$, both countries adopt *lassez faire* policy. Under (FDI, Ex) and (Ex, FDI), the host countries of FDI, i.e. South and North respectively, both set their emission stand at 0, the most stringent form of environmental policy. These two tables lead to the following proposition.

Proposition 2 *The liberalization of FDI may strengthen the emission standard of the host country of FDI, making the environmental policy of the host country more stringent, which is contrary to the "race to the bottom" effect.*

Proof. In Table 1 and 2, technology gap between the North and South countries is small, i.e. $\theta_n < \theta_s < \frac{3}{2}\theta_n$, and the market size of countries is not very larger, i.e. $a < \frac{\left(3\theta_s^2+\theta_n^2-2\theta_s\theta_n\right)}{2(\theta_s-\theta_n)}$,

1. In Table 1, changing from (Ex, Ex) to (FDI, Ex), the emission standard of the South decreases from $a+\frac{\theta_n}{2}-\frac{3\theta_s}{2}$, which is a positive value $2\theta_s-\theta_n < a < 2\theta_n$, to 0; changing from (Ex, Ex) to (Ex, FDI), the emission standard of the North decreases from

$a+\theta_n-2\theta_s$, which is above 0, to 0; changing from (Ex, Ex) to (FDI, FDI), the emission standards of the North and South countries respectively decrease from $a+\theta_n-2\theta_s$ and $a+\frac{\theta_n}{2}-\frac{3\theta_s}{2}$ to $\frac{(\theta_s-\theta_n)}{2}$ $\left(< a+\theta_n-2\theta_s, \text{ if } \theta_s < \frac{7\theta_n}{5} \text{ and } \frac{5\theta_s}{2}-\frac{3\theta_n}{2} < a < 2\theta_n\right)$ and 0.

2. In Table 2, changing from from (Ex, Ex) to (FDI, Ex), the emission standard of the South decreases from θ_s to 0; changing from (Ex, Ex) to (Ex, FDI), the emission standard of the North decreases from θ_n to 0; changing from (Ex, Ex) to (FDI, FDI), the emission standards of the North and South countries respectively decrease from θ_n and θ_s to $\frac{(\theta_s-\theta_n)}{2}$ and 0.

■

As clarified above, the results of this model is not one sided. Table 3 below offers a different case.

Table 3. Equilibria of Emission Standard with $2\theta_n<\theta_s<3\theta_n$ and $4\theta_s-2\theta_n<a$

╲	(Ex, Ex)	(FDI, Ex)	(Ex, FDI)	(FDI, FDI)
z_n^*	θ_n	θ_n	0	$\frac{(\theta_s-\theta_n)}{2}$
z_s^*	θ_s	θ_s	θ_s	θ_s

In this case, the emission standard of South takes the laxest form in all FDI-export scenarios.

Proposition 3 *The liberalizaion of FDI may not make the emission standard of the host country more stringent, which supports the "regulatory chill" hypothesis.*

Proof. In Table 3, technology gap between between the North and South countries is moderate, i.e. $2\theta_n < \theta_s < 3\theta_n$, and the market size of countries is larger enough, i.e. $4\theta_s - 2\theta_n < a$. When changing from (Ex, Ex) to (FDI, Ex), the host country of FDI, South, holds its emission standard at θ_s; when changing from (Ex, Ex) to (FDI, FDI), the South still holds its emission standard at θ_s. ■

4 FDI Equilibrium

We solve the market share game using backward induction. In the preceeding section, equilibria of emission standards under different FDI-export scenarios are obtained as best reactions of governments to firms FDI decisions. With these best responses, it is easy to compute the profits of firms under various FDI-export scenarios.

The game that firms interactively make decisions FDI can be modelled as a static form game (see Figure 1), denoted by FDI-Export game.

Figure 1. FDI-Export Game

		North Firm	
		Export	FDI
South Firm	Export	π_s^{EE},π_n^{EE}	π_s^{FE},π_n^{FE}
	FDI	π_s^{EF},π_n^{EF}	π_s^{FF},π_n^{FF}

In this game, a firm strategically decides whether to carry out FDI, it does not only consider whether it can earn a higher profit under FDI than under export in the foreign market, but also take into account the impact of its decision on its profit in home market. In this case, if upon FDI, the increase of firm's domestic profit is more than offset the loss of its foreign profits, FDI strategy will be chosen.

In this section, according to Table 1, we have

$$\pi_n^{FE} - \pi_n^{EE} = \frac{a^2}{9} + \frac{20a\theta_s}{9} - \frac{22a\theta_n}{9} - \frac{41{\theta_s}^2}{36} + \frac{\theta_n\theta_s}{18} + \frac{43{\theta_n}^2}{36} - F, \quad (41)$$

$$\pi_n^{FF} - \pi_n^{EF} = \frac{a^2}{9} - \frac{5a\theta_n}{9} + \frac{a\theta_s}{3} + \frac{4{\theta_n}^2}{9} - \frac{\theta_n\theta_s}{3} - F, \quad (42)$$

$$\pi_s^{EF} - \pi_s^{EE} = \frac{a^2}{9} - \frac{4a\theta_s}{9} + \frac{2a\theta_n}{9} + \frac{4{\theta_s}^2}{9} - \frac{4\theta_n\theta_s}{9} + \frac{{\theta_n}^2}{9} - F, \quad (43)$$

$$\pi_s^{FF} - \pi_s^{FE} = \frac{a^2}{9} + \frac{a\theta_n}{9} - \frac{a\theta_s}{3} + \frac{{\theta_n}^2}{36} - \frac{\theta_n\theta_s}{6} + \frac{{\theta_s}^2}{4} - F. \quad (44)$$

To simplify the notation, let $F_1 = \frac{a^2}{9} + \frac{20a\theta_s}{9} - \frac{22a\theta_n}{9} - \frac{41{\theta_s}^2}{36} + \frac{\theta_n\theta_s}{18} + \frac{43{\theta_n}^2}{36}$, $F_2 = \frac{a^2}{9} - \frac{5a\theta_n}{9} + \frac{a\theta_s}{3} + \frac{4{\theta_n}^2}{9} - \frac{\theta_n\theta_s}{3}$, $F_3 = \frac{a^2}{9} - \frac{4a\theta_s}{9} + \frac{2a\theta_n}{9} + \frac{4{\theta_s}^2}{9} - \frac{4\theta_n\theta_s}{9} + \frac{{\theta_n}^2}{9}$ and $F_4 = \frac{a^2}{9} + \frac{a\theta_n}{9} - \frac{a\theta_s}{3} + \frac{{\theta_n}^2}{36} - \frac{\theta_n\theta_s}{6} + \frac{{\theta_s}^2}{4}$. Therefore (41), (42), (43) and (44) are simplified as $\pi_n^{FE} - \pi_n^{EE} = F_1 - F$, $\pi_n^{FF} - \pi_n^{EF} = F_2 - F$, $\pi_s^{EF} - \pi_s^{EE} = F_3 - F$ and $\pi_s^{FF} - \pi_s^{FE} = F_4 - F$.

Proposition 4 *The Nash equilibrium of the FDI-Export game is contingent on the value of fixed cost of building a new plant abroad,*

1. *If $F > F_1$, then the Nash equilibrium is that both firm choose to sale abroad through export;*
2. *If $F_1 > F > F_4$, the Nash equilibrium is unilateral FDI from North to the South;*
3. *If $F_4 > F > 0$, the Nash equilibrium is bilateral FDI.*

Proof. The first step is to compare F_1, F_2, F_3 and F_4 with each other. Since $a > \theta_s > \theta_n$,

- $F_1 - F_2 = \frac{(\theta_s - \theta_n)}{36}(68a - 41\theta_s - 27\theta_n) > 0$;
- $F_2 - F_3 = \frac{(\theta_s - \theta_n)}{9}(7a - 4\theta_s - 3\theta_n) > 0$;
- $F_2 - F_4 = \frac{(\theta_s - \theta_n)}{12}(8a - 3\theta_s - 5\theta_n) > 0$, and $F_4 = \frac{1}{36}(2a + \theta_n - 3\theta_s)^2 > 0$.

According to the comparison above,, there is $F_1 > F_2 > F_3$ and F_4. When $F > F_1$, to export is the dominant strategy for both firms, so the equilibrium is no FDI in this case; when $F_1 > F > F_2$, to export is the dominant strategy for the southern firm, and $\pi_n^{FE} - \pi_n^{EE} = F_1 - F > 0$, so the equilibrium in this case is unilateral FDI from North to the South; when $F_2 > F$, only the sign $\pi_s^{FF} - \pi_s^{FE} = F_4 - F$ matters, because to carry out FDI is dominant strategy for the northern firm. When $F_2 > F > F_4$, the equilirium is also unilateral FDI from North to South; when $F_4 > F > 0$, the equilibrium is bilateral FDI. ■

The result here is the typical extension of proximity-concentration framework of FDI.

5 Concluding Remarks

This paper studies the interrelationship between FDI and environmental policy using a North-South model in market share game. The policy instrument considered in the model is a conventional CAC one, emission standard, which does not generate any fiscal revenue for a government.

The trade cost in the current paper is endogenous tariff, similar to the melting-iceberg trade cost. With this assumption, it can be proven that if the southern firm exports, then it will export, because the fact that trade cost will overweigh its profit preventing it from exporting a positive quantity to the foreign market.

An important finding of this paper is that whether FDI will make countries' environmental policies more stringent or lax may depend on the technology gap and market sizes of the countries. In this model, we find that if the South only has a small lag in technology and both markets are small, the host country of the FDI may loosen it emission standard upon FDI liberalization, causing "race to the bottom" effect. If countries' technology gap is moderate and market sizes are sufficiently large, then the South is reluctant to tighten its emission standard, i.e., "regulatory chill" hypothesis may hold.

As an usual exercise, FDI versus export as strategies to serve foreign markets, are characterized. Conditions for which that both countries choose to export, unilateral FDI from North to South, and bilateral FDI in equilibrium are given.

The limitation of the model is that it does not consider employment concerns, spillover of technology and R&D, and the like, representing some important dimensions of the interrelationship between FDI and environment policies. Future research may include these factors, preferablly in a dynamic model.

6 Appendix A

According to the objective funcions of North and South firms in subsection 3.2, the optimal production levels of every firms in each market can be solved out

$$q_s^{s*} = \frac{a - 2c_s(e_{ss}) + c_n(e_{ns})}{3}, \tag{45}$$

$$q_s^{n*} = \frac{a - 2c_s(e_{ss}) + c_n(e_{nn}) - 2T_n}{3}, \tag{46}$$

$$q_n^{n*} = \frac{a - 2c_n(e_{nn}) + c_s(e_{ss}) + T_n}{3}, \tag{47}$$

$$q_n^{s*} = \frac{a - 2c_n(e_{ns}) + c_s(e_{ss})}{3}. \tag{48}$$

In this FDI-export scenario, the total amount of world emission is $E^{FE} = (q_s^{s*} + q_s^{n*}) e_{ss} + q_n^{s*} e_{ns} + q_n^{n*} e_{nn}$, so the expressions of social welfare are

$$W_s^{FE} = \frac{Q_s^2}{2} + \pi_s^{FE} - D\left(\left(q_s^{s*} + q_s^{n*}\right) e_{ss} + q_n^{s*} e_{ns} + q_n^{n*} e_{nn}\right), \tag{49}$$

$$W_n^{FE} = \frac{Q_n^2}{2} + \pi_n^{FE} + T_n q_s^{n*} - D\left(\left(q_s^{s*} + q_s^{n*}\right) e_{ss} + q_n^{s*} e_{ns} + q_n^{n*} e_{nn}\right). \tag{50}$$

Substitute (47), (46) into (50), and maximize W_n^{FE} w.r.t T_n, we can find the optimal tariff

$$T_n^* = \frac{a - c_s(e_{ss}) - e_{nn} + 2e_{ss}}{3}. \tag{51}$$

Substitute (51) into (46), we can obtain

$$q_s^{n*} = \frac{a - 4\theta_s + 3\theta_n - e_{nn}}{9}$$

Since there are also $e_{ss} = z_s \le \theta_s$, $e_{nn} = z_n \le \theta_n$, the equilibirum of emission standard of North is

$$z_n^* = \begin{cases} a + \frac{\theta_s}{2} - \frac{3\theta_n}{2}, \text{ if } \frac{3\theta_n}{2} - \frac{\theta_s}{2} < a \le \frac{5\theta_n}{2} - \frac{\theta_s}{2}; \\ \theta_n, \text{ if } a > \frac{5\theta_n}{2} - \frac{\theta_s}{2}. \end{cases}$$

Then following the proof of proposition in subsection 3.1, it is easy to prove that $q_s^{n*} = 0$, if $\theta_s < a \le 4\theta_s - 2\theta_n$; $q_s^{n*} > 0$, if $a > 4\theta_s - 2\theta_n$.

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