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ORIGINAL ARTICLE

FDI and environmental regulation: pollution haven or a race to the top?

Baomin Dong · Jiong Gong · Xin Zhao

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Abstract Increasing foreign direct investment (FDI) flows accompanied with globalization have raised the concern of a "race to the bottom" phenomenon in environmental protection. This is because footloose investors of "dirty" industries tend to relocate to "pollution havens" of the developing world. However when pollutant is transboundary (as in the case of greenhouse gases), the source country's incentive to relocate and the recipient country's willingness to host such industries are not straightforward. This article studies the relationship between FDI and environmental regulation using a North–South market share game model in a two-country setting, when pollution is transboundary. Contrary to the pollution haven hypothesis, our model shows that if market sizes of the two countries are small, FDI will raise the emission standard of the host country, resulting in a "race-to-the-top" phenomenon; but if market sizes are large enough, FDI will not change the emission standard of the South (from its laxest form), a finding that is consistent with the "regulatory chill" argument. Equilibrium FDI is contingent on the fixed cost of FDI, as the traditional proximity–concentration tradeoff theory predicts.

Keywords FDI · Emission standard · Race to the bottom · Regulatory chill

B. Dong (✉)
School of Economics, Zhejiang University, Beijing 100029, China
e-mail: baomindong@uibe.edu.cn

B. Dong · J. Gong
School of International Trade and Economics, University of International Business and Economics, Beijing 100029, China
e-mail: johngong@gmail.com

X. Zhao
Department of Economics, University of Toronto, Toronto, ON M5S 3G7, Canada
e-mail: xinzhao1985@hotmail.com

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1 Introduction

While climate change is a global concern, industrialized and developing countries have not been unanimous on the responsibilities to reduce greenhouse gas (GHG) emissions and the related regulatory mechanisms. The United States, Canada, Australia and several other countries were reluctant to be signatories of the Kyoto Protocol. The Copenhagen summit in December 2009 ended as a debacle without reaching any substantive agreement. Apparently strategic actions by various countries are motivated by the economic impact of proposed measures to reduce GHG emissions.

International flows of goods and services obviously enter into this debate. Nations may independently engage in a race-to-the-bottom[1] regulatory practice by setting weak environmental standards in order to gain strategic trade advantages, as they would argue they are still on the climbing side of the environmental Kuznets curve. They may also be motivated to respond to the relocation of multinational enterprises (MNEs) of dirty industries seeking to economize their cost of production and gain competitive edges in international markets. This is what is termed the "pollution haven hypothesis" (PHH) for which the literature has seen mixed empirical evidence so far.[2]

Some empirical studies examine individual footloose plant location decisions, whereas others consider the leakage effect that takes the form of international trade where firms with dirty production in countries with low emission standards expand output. Early papers show that PHH is difficult to establish empirically, except a few recent studies[3] which have demonstrated small but statistically significant pollution haven effects.[4]

Prior literature focused on the leakage effect on PHH resulting from trade. However FDI across the globe has increased rapidly in recent decades. Sales of foreign affiliates of MNEs have almost doubled the value of global exports of goods and non-factor services in recent years. According to the World Investment Report 2009, global FDI amounted to $1.2 trillion in 2009 and it is projected to reach $1.8 trillion in 2011. Increasing FDI flows may have a worrisome impact on a host country's ecosystem, and the global environment in the case of transboundary pollution. Despite the importance of FDI in today's economy, its relationship with environmental policies has not been extensively discussed at a theoretical level in the existing literature. The current article attempts to fill this gap.

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[1] Refers to what occurs when foreign direct investment (FDI) host countries attempt to exempt firms from or generally loosen their environmental regulatory requirements in order to attract dirty industries.

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

[3] For instance, Wagner and Timmins (2009) find robust evidence of a pollution haven effect for the chemical industry.

[4] Keller and Levinson (2002), Levinson (1996a,b) and Leonard (1988). Becker and Henderson (2000), Greenstone (2002) and List et al. (2003) consider plant locations, and Ederington and Minier (2003) on international trade. Jaffe et al. (1995), Dean (1992, 2001), Copeland and Taylor (2004) and Brunnermeier and Arik (2004) offer surveys of the literature.

As mentioned above, empirical papers testing PHH provide mixed results. Papers supporting the hypothesis include Gray (2002) and Xing and Kolstad (2002) among others. Gray (2002) points out that such a negative relationship may be industry-specific, for example, the furniture industry. Xing and Kolstad (2002) adopt a new measure for the stringency of environmental regulation and find that for a pollution-intensive industry, lax environmental policies attract foreign investment. Using a Chinese panel dataset, Zhang and Fu (2008) find that FDI prefers to locate in regions with relatively weak environmental regulations. Aliyu (2005) concludes that environmental policy is important in explaining the outflow of FDI from OECD countries to less developed countries. Keller and Levinson (2002) find robust evidence that pollution costs have a moderate deterrent effect on foreign investments into US states. Condliffe and Morgan (2009) use county-level data in the US to find correlation between lax environment standards and decisions of new plant locations.

Another line of work (Levinson 1996a,b; Letchumanan and Kodoma 2000; Eskeland and Harrison 2003) however find no significant correlation between MNEs' site location decisions and environmental regulation in host countries. Shen (2008) and Fabry and Zenghi (2002) find no PHH supporting evidence in China. Smarzynska and Wei (2001) also do not find sound support for this hypothesis. A recent paper by Dean et al. (2009) uses Chinese data to find equity joint ventures funded from industrialized countries are not significantly attracted by weak environmental standards, regardless of the pollution intensity of the industry. Finally, some papers argue that PHH is still valid even though empirical evidence is insignificant. For instance, Millimet and List (2004) claim that the impact of stricter regulation is heterogeneous spatially, varying systematically based on location-specific attributes as opposed to the traditional PHH theory of a homogenous response.

At the theoretical level, there are also some diverging predictions. Wu (2004) finds that private information may constitute information rent for the MNEs; the strategic information-rent extraction behavior of the governments then weakens the PHH. Using a political economy model with FDI liberalization, Cole et al. (2006) find that, with a low degree of corruptibility, the environmental tax rate of a country increases with the number of foreign firms located in the host country. 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 the host country's emission standards if the reservation profit of firms is very high. Using a market share game for optimal emission tax, De Santis and Stähler (2008) conclude that liberalization of FDI drives the host countries of FDI to impose a higher environmental tax rate, which is actually a Pigouvian tax rate. Eskeland and Harrison (2003) find that the relationship between FDI and pollution intensity depends upon the pollutant. Smarzynska and Wei (2001) assume that FDI is a tradeoff between host country's corruption level and laxity of environmental controls.

Note that, to date, the theory surrounding PHH has focused on both types of pollutants, i.e., global (Copeland and Taylor 1995, 2005) and local (Copeland and Taylor 1994, 2003). Silva and Zhu (2009) considered the case of emission of global and local pollutants together in the production process. As global warming has become a major threat to human developments, modeling PHH in a global pollutant context appears to be more urgent.

The current article considers a reciprocal FDI/trade model with endogenously determined tariffs, environmental standards, and FDI decisions. Hence, this article differs from existing papers in that the analytical framework is rich enough to accommodate the PHH, race-to-the-bottom, race-to-the-top, and regulatory chill phenomena.

Second, we endogenize a firm's FDI decision by allowing for its optimized choice between FDI and export based on the proximity–concentration theory. Trade is obviously relevant to transboundary pollution issues such as GHG emissions. Some of the empirical studies consider the pollution leakage effect taking the form of international trade. The proximity–concentration theory analyzes the decision of firms on how to serve a foreign market. It explains two-way intra-industry affiliates' production–trade activities versus FDI activities, and has become the standard analytical framework for the new trade theory (Brainard 1997; Helpman 2006). Under this framework, firms have to export or establish an affiliate and produce abroad. Proximity to the customers abroad saves trade costs while concentration of production at home and exporting overseas saves additional fixed costs. Firms choose between the two alternatives by comparing their respective profits.

Another differentiating feature of the current article is the use of a game theoretical approach, as we believe the inclusion of strategic interactions among countries and MNEs is absolutely necessary in modeling relationships between FDI and environmental policies. Fredriksson and Millimet (2002) and Fredriksson et al. (2004) show evidence that U.S. states set environmental regulations strategically based on the regulations of neighboring states. Due to the lack of international coordination and enforcement of environmental issues, strategic interactions are even more important in a cross-country setting, implying that the PHH phenomenon may well exist and persist. Indeed, a recent paper by Kellenberg (2009) finds empirical confirmation of PHH in a cross-country context by accounting for strategically determined environmental, trade, and intellectual property right (IPR) policies. It is found that for the top 20th percentile of countries in terms of growth attributed to U.S. multinational affiliates between 1999 and 2003, as much as 8.6% of that growth can be attributed to relaxing enforcement of environmental policies. Of the developing and transition countries in the top 20th percentile of countries in terms of growth attributed to U.S. multinational affiliates, approximately 32% of that growth can be related to falling levels of stringency in environmental enforcement[5].

In our model, the game played is market share game, that is, firms move before governments make policy decisions. Note that the environmental policy instrument in this model is emission standard which is different from Cole et al. (2006) and De Santis and Stähler (2008), whose policy instrument 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 generates revenues for the government on the other hand, is a typical type of market-based

[5] In fact, Ederington et al. (2005), Kahn and Yoshino (2004) and Ederington and Minier (2003) already find evidence that United States imports are responsive to changes in environmental stringency but they did not offer strategic behavior based estimation.

incentive (MBI) instrument. Fullerton (2001) 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 may be more efficient in monitoring and enforcement when information is asymmetric between the regulator and the regulated.

The model of this article combines countries' technology asymmetry, endogenous tariffs (i.e., endogenous trade cost), transboundary pollution, and optimal emission standards together. The main results of this article are that (i) if market sizes of the two countries (North and South country) are small, FDI raises the emission standard of the host country, resulting in a race-to-the-top[6] phenomenon; if market sizes of the two countries are large enough, FDI does not change the emission standard of the South with laxest forms of regulation, resulting in a regulatory chill phenomenon; (ii) the import barrier set by the North is prohibitive in equilibrium when market sizes of both countries are not large enough, and the Southern firm can only get access to the Northern market through FDI; (iii) Equilibrium FDI is contingent on the fixed cost of FDI, as the traditional proximity–concentration tradeoff theory predicts.

The results of our article have policy implications in light of the global climate change negotiation. The disappointing outcome of the Copenhagen summit is largely due to the disagreement between developed and developing countries in their commitment to reduce GHG emissions. Our model indicates that trading countries of small market sizes may have self-interest in introducing stringent emission regulations such that the concern over the PHH phenomenon may be exaggerated for these countries. Trading countries of large market sizes on the contrary, may lead to the "regulatory chill" effect, which should be the focus of the global climate negotiations. The case of trade between US and China naturally comes to mind, underlining the importance of climate negotiations between these countries. This is not just because of the absolute amount of pollution these countries generate, but more importantly because they are more likely to go the route of racing to the bottom of environmental standards in the wake of increasing global flow of goods, services and capital.

The rest of the article is organized as follows: Sect. 2 introduces the basic model. Section 3 discusses the equilibria of emission standards under different FDI–export scenarios for firms, Sect. 4 studies the FDI equilibrium, and Sect. 5 concludes the model with some discussions of policy implications.

2 The model

There are two countries in our model, a northern country and a southern country. Each country has one firm. The firms compete *à la* Cournot. The countries differ in their production technologies; the North is endowed with a cleaner technology, that is, when producing the same amount of output, the northern firm emits less than the southern one does. Pollution is completely transboundary, as in the case of GHG emission.

[6] Umanskaya and Barbier (2008) obtain the result where pollution haven may arise in the North. They argue that if the relative factor price differential effect overwhelms the environmental policy differential effect, a true pollution haven may be created in the rich country. However the model is based on a traditional Heckcher–Ohlin framework without strategic considerations.

Firms in both countries serve their domestic markets. They may, at the same time serve foreign markets through export or FDI (but not both export and FDI). Export is subject to an optimal tariff set unilaterally by the receiving country. If the firm serves the foreign market through FDI, it faces a fixed lump sum cost associated with building up a new plant. Firms' FDI decision is based on the proximity–concentration tradeoff.

The game played in this model is the market share game in which firms make decisions before governments do. Our setup differs from the race-to-the-bottom game seen in several previous papers where governments make decisions on environmental policies first. The order of the play is as follows:

Stage 1: Each firm chooses its international market strategy, i.e., export or FDI;
Stage 2: Given firms' decisions, governments set their welfare-maximizing emission standards;
Stage 3: Firms choose their abatement technology (emission levels) in response to 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 the social 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 sold in its home market, while q_j^i is the quantity of firm j $(\neq i)$ sold in its foreign market, i.e., market i.

Denote $z_i, i \in \{n, s\}$ as 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 per-unit emission level chosen by firm i when it produces 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 article), then $0 \leq e_{ij} \leq \min\left\{\theta_i, z_j\right\}$, and $\theta_i - e_{ij}$ is the amount of abatement. The North has cleaner technology, or $\theta_n < \theta_s$. μ_i is the marginal cost of abatement, and c_{i0} is the portion of the marginal cost of production that is independent of emission abatement. To simplify the discussion in the rest of the article, without loss of generality, we can assume that $c_{i0} = 0$, $\mu_i = 1$, i.e., $c_i\left(e_{ij}\right) = \theta_i - e_{ij}$, where $\theta_i < a$.

The pollution 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 world emissions, and ω describes the seriousness of the environmental problem. Assume in this model that $\omega = 1$ without loss of generality.

Denote T_i as the tariff of country i on the foreign firm. Fixed cost of establishing a foreign subsidiary 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 worst polluting firm's unit product emission level θ in its country. For firm i producing goods in country j, $e_{ij} = \min\left\{\theta_i, z_j\right\}$. In the current model, more emissions incur no cost to firms, so a profit-maximizing firm chooses its emission level of $\min\left\{\theta_i, z_j\right\}$.

3.1 No FDI

Consider first the case in which firms from both the North and the South are restrained from FDI, so that they can only enter foreign markets via exports. The objective functions of the firms in the South and the North are respectively

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

$$\underset{\{q_n^n, q_n^s\}}{\text{Max}}\ \pi_n^{EE} = \left(a - q_n^n - q_s^n - c_n\left(e_{nn}\right)\right) q_n^n + \left(a - q_s^s - q_n^s - c_n\left(e_{nn}\right) - T_s\right) q_n^s, \tag{2}$$

where superscript EE stands for the case in which both countries serve foreign markets through exports. The first terms on the RHS of (1) and (2) are the firms' profits obtained in their home markets, whereas the second terms are profits from exports. Exports q_s^n and q_n^s should be nonnegative quantities.

For the southern firm, output levels in the domestic and foreign markets are respectively

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

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

where superscript "$*$" stands for the equilibrium levels of production.

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

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

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

When firms are restrained from FDI, they set their emission levels according to the emission standard of their home countries. In this case, the global emission level is $E^{EE} = \left(q_s^{s*} + q_s^{n*}\right) e_{ss} + \left(q_n^{n*} + q_n^{s*}\right) e_{nn}$. The social welfare maximization of the southern and northern countries in the no-FDI case can be expressed as

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

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

The components of social welfare under this scenario include consumer surplus $\left(\frac{Q_s^2}{2} \text{ and } \frac{Q_n^2}{2}\right)$, firm profits, tariff revenue $\left(T_s q_n^{s*}, T_n q_s^{n*}\right)$, and the resulting environmental damage. Substituting (3), (4), (5), (6) into (7) and (8), optimal tariffs of the South and North are then obtained as follows,

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

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

This result leads to the following proposition, whose proof is provided in Appendix A.

Proposition 1 *If FDI is not allowed, and the markets of these countries are small* (*that is,* $\theta_s < a \leq 4\theta_s - 2\theta_n$)*, the tariff in the North is prohibitively high that prevents the southern firm from exporting to the North in equilibrium, i.e.,* $q_s^{n*} = 0$*; when the markets of these countries are large enough* (*that is,* $a > 4\theta_s - 2\theta_n$)*, the southern firm exports to the North.*

Intuitively, when the market demand is small, the benefit for the North in terms of improving environmental quality arising from deterring the imports of a polluting industry from the South outweighs the loss of consumer surplus. However, when markets are large, this tradeoff is reversed.

To obtain the equilibrium emission standards, substituting the optimal quantity levels in Eqs. 3–6 and optimal tariffs in (9) and (10) into (7) and (8), we write the following welfare functions of North and South as functions of environmental standards:

$$\begin{aligned} W_s^{EE}\left(z_s, z_n\right) = &-\frac{1}{2} z_n a + \frac{1}{2} z_n \theta_n - \frac{1}{2} {z_n}^2 + \frac{7}{18} a^2 - \frac{1}{9} a\theta_n + \frac{2}{9} a z_s - \frac{2}{3} a\theta_s \\ &+ \frac{2}{9} {\theta_n}^2 + \frac{1}{9} \theta_n z_s - \frac{1}{3} \theta_n \theta_s - \frac{1}{9} {z_s}^2 - \frac{1}{3} z_s \theta_s + \frac{1}{2} \theta_s, \end{aligned} \tag{11}$$

$$\begin{aligned} W_n^{EE}\left(z_s, z_n\right) = &\frac{1}{9} z_n z_s - \frac{1}{3} z_n \theta_s + \frac{5}{36} z_n a + \frac{7}{36} z_n \theta_n - \frac{1}{8} {z_n}^2 + \frac{251}{648} a^2 - \frac{275}{324} a\theta_n \\ &- \frac{38}{81} a z_s + \frac{2}{27} a\theta_s + \frac{371}{648} {\theta_n}^2 - \frac{10}{81} \theta_n z_s - \frac{8}{27} \theta_n \theta_s - \frac{44}{81} {z_s}^2 + \frac{16}{27} z_s \theta_s \\ &+ \frac{1}{9} {\theta_s}^2. \end{aligned} \tag{12}$$

Differentiating (11) and (12) with respect to their own-country emission standards respectively yields the first order conditions:

$$\frac{\mathrm{d}W_s^{EE}(z_s, z_n)}{\mathrm{d}z_s} = \frac{2a + \theta_n - 3\theta_s - 2z_s}{9} = 0,$$
$$\frac{\mathrm{d}W_n^{EE}(z_s, z_n)}{\mathrm{d}z_n} = \frac{5a + 7\theta_n - 12\theta_s + 4z_s - 9z_n}{36} = 0.$$

The equilibrium emission standards are then obtained as below:

$$\left(z_s^*, z_n^*\right) = \begin{cases} \left(a + \frac{\theta_n}{2} - \frac{3\theta_s}{2}, a + \theta_n - 2\theta_s\right), & \text{if } 2\theta_s - \theta_n < a < 2\theta_s; \\ \left(a + \frac{\theta_n}{2} - \frac{3\theta_s}{2}, \theta_n\right), & \text{if } 2\theta_s \leq a < \frac{5\theta_s}{2} - \frac{\theta_n}{2}; \\ \left(\theta_s, \theta_n\right), & \text{if } a \geq \frac{5\theta_s}{2} - \frac{\theta_n}{2}. \end{cases} \tag{13}$$

As pointed out by Markusen et al. (1995), analysis of FDI and trade under imperfect competition can be complicated because firms may change the location and number of their plants, thus making the reaction curves in a Cournot model discontinuous. Naturally one would expect that many of the equilibrium solutions in this article are discontinuous. It is clear in (13) that the North always has stricter emission standards than the South. This result also indicates that the countries' emission standards become more stringent as the market size of the countries becomes larger, i.e., as a increases, z_s^* and z_n^* increase untill they reach their upper bounds θ_s and θ_n respectively.

3.2 Unilateral FDI from North to South

This subsection considers the case in which the northern firm serves the southern market through FDI, while the southern firm serves the northern market through exports (superscript FE is used to label this case). When the northern firm establishes a new plant in the South instead of exporting, it will not incur trade cost (the tariff); however, there is a fixed cost for FDI, F. The objective functions of the southern and northern firms in this case are, respectively,

$$\underset{\{q_s^s, q_s^n\}}{\text{Max}}\ \pi_s^{FE} = \left(a - q_s^s - q_n^s - c_s\left(e_{ss}\right)\right) q_s^s + \left(a - q_n^n - q_s^n - c_s\left(e_{ss}\right) - T_n\right) q_s^n, \tag{14}$$

$$\underset{\{q_n^n, q_n^s\}}{\text{Max}}\ \pi_n^{FE} = \left(a - q_n^n - q_s^n - c_n\left(e_{nn}\right)\right) q_n^n + \left(a - q_s^s - q_n^s - c_n\left(e_{ns}\right)\right) q_n^s - F. \tag{15}$$

Compared with (2), the northern firm's profit gained from the South changes from $\left(a - q_s^s - q_n^s - c_n\left(e_{nn}\right) - T_s\right) q_n^s$ to $\left(a - q_s^s - q_n^s - c_n\left(e_{ns}\right)\right) q_n^s - F$, and the endogenous trade cost $T_s q_n^s$ is replaced by the fixed cost F for establishing a subsidiary overseas.

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

The emissions of the northern subsidiary plant in the South must comply with 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, it must be the case that $e_{ns} = \min\{\theta_n, z_s\}$. As for e_{ss} and e_{nn}, the emission levels of firms when they produce goods in their home markets, still we have $e_{ss} = z_s \leq \theta_s$, $e_{nn} = z_n \leq \theta_n$. $\theta_n < \theta_s$, so it is plausible that the southern regulator sets an emission standard $z_s \in (\theta_n, \theta_s)$. In that case, $e_{ns} = \theta_n$.

Global emissions in this case are $E^{FE} = \left(q_s^{s*} + q_s^{n*}\right) e_{ss} + q_n^{s*} e_{ns} + q_n^{n*} e_{nn}$. The social welfare functions of the South and the North are, respectively

$$W_s^{FE} = \frac{Q_s^2}{2} + \pi_s^{FE} - D\left(\left(q_s^{s*} + q_s^{n*}\right) e_{ss} + q_n^{s*} e_{ns} + q_n^{n*} e_{nn}\right), \quad (16)$$

$$W_n^{FE} = \frac{Q_n^2}{2} + \pi_n^{FE} + T_n q_s^{n*} - D\left(\left(q_s^{s*} + q_s^{n*}\right) e_{ss} + q_n^{s*} e_{ns} + q_n^{n*} e_{nn}\right). \quad (17)$$

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 these countries, obtained by maximizing relevant social welfare functions, are

$$\left(z_s^*, z_n^*\right) = \left(\min\{a - \theta_s + \theta_n, \theta_s\}, \min\{a - \theta_n, \theta_n\}\right). \quad (18)$$

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 is also concave in z_s and z_n. Similarly, maximizing the social welfare functions yields the equilibrium emission standards as,

$$\left(z_s^*, z_n^*\right) = \left(0, \min\{a - \theta_n, \theta_n\}\right). \quad (19)$$

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} in these two cases,

$$W_s^{FE} \mid_{(z_s^*, z_n^*) = (\min\{a-\theta_s+\theta_n, \theta_s\}, \min\{a-\theta_n, \theta_n\})} - W_s^{FE} \mid_{(z_s^*, z_n^*) = (0, \min\{a-\theta_n, \theta_n\})} \quad (20)$$
$$= \begin{cases} \frac{1}{6}a^2 - \frac{1}{3}a\theta_s + \frac{1}{6}\theta_s^2 - \frac{1}{3}\theta_n\theta_s, \text{ if } a < 2\theta_s - \theta_n; \\ \frac{1}{3}a\left(\theta_s - \theta_n\right) - \frac{1}{6}\theta_n^2 - \frac{1}{2}\theta_s^2 + \frac{1}{3}\theta_n\theta_s, \text{ if } 2\theta_s - \theta_n \leq a \leq 4\theta_s - 2\theta_n; \\ a\left(\frac{2}{9}\theta_s - \frac{1}{3}\theta_n\right) - \frac{1}{6}\theta_n^2 - \frac{1}{18}\theta_s^2 + \frac{1}{9}\theta_n\theta_s, \text{ if } a > 4\theta_s - 2\theta_n. \end{cases}$$

It is obvious that the LHS of (20) is contingent on the parameter conditions. The result implies that the equilibrium emission standards can be $\left(z_s^*, z_n^*\right) = (a - \theta_s + \theta_n, a - \theta_n)$, or $\left(z_s^*, z_n^*\right) = (a - \theta_s + \theta_n, \theta_n)$, or $\left(z_s^*, z_n^*\right) = (\theta_s, \theta_n)$, or $\left(z_s^*, z_n^*\right) = (0, a - \theta_n)$, or $\left(z_s^*, z_n^*\right) = (0, \theta_n)$ when the northern firm resorts to FDI while the southern firm serves the foreign market via exports. From these listed equilibria, it is learned that it is plausible that the South, the host country for the FDI, sets more stringent emission standards than does the North, a scenario that would happen in the case in which FDI is not allowed.

3.3 Unilateral FDI from South to North

In Sects. 3.1 and 3.2, it is shown that exports of the southern firm may shrink to zero. This subsection investigates that whether FDI can serve as a perfect substitute for exports. The objective functions of the southern and northern firms are, respectively

$$\underset{\{q_s^s, q_s^n\}}{\text{Max}}\ \pi_s^{EF} = \left(a - q_s^s - q_n^s - c_s\left(e_{ss}\right)\right) q_s^s + \left(a - q_n^n - q_s^n - c_s\left(e_{sn}\right)\right) q_s^n - F, \tag{21}$$

$$\underset{\{q_n^n, q_n^s\}}{\text{Max}}\ \pi_n^{EF} = \left(a - q_n^n - q_s^n - c_n\left(e_{nn}\right)\right) q_n^n + \left(a - q_s^s - q_n^s - c_n\left(e_{nn}\right) - T_s\right) q_n^s. \tag{22}$$

where superscript EF stands for the case in which the northern firm exports and the southern firm is the source of FDI. The second term on the RHS of (21), $\left(a - q_n^n - q_s^n - c_s\left(e_{sn}\right)\right) q_s^n - F$, is the profit reaped by the southern firm as a result of FDI. The southern firm's output sold in the North is $c_s\left(e_{sn}\right)$, because under FDI the southern firm has to comply with the emission standards set by the northern regulator.

The global emissions in this case are $E^{EF} = q_s^{s*} e_{ss} + q_s^{n*} e_{sn} + \left(q_n^{n*} + q_n^{s*}\right) e_{nn}$. The social welfare functions for the South and North are respectively

$$W_s^{EF} = \frac{Q_s^2}{2} + \pi_s^{EF} + T_s q_n^{s*} - D\left(q_s^{s*} e_{ss} + q_s^{n*} e_{sn} + \left(q_n^{n*} + q_n^{s*}\right) e_{nn}\right), \tag{23}$$

$$W_n^{EF} = \frac{Q_n^2}{2} + \pi_n^{EF} - D\left(q_s^{s*} e_{ss} + q_s^{n*} e_{sn} + \left(q_n^{n*} + q_n^{s*}\right) e_{nn}\right). \tag{24}$$

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 will set an emission standard $z_n \in (\theta_n, \theta_s)$ to strengthen the competitive advantage of the northern firm.

Similar to the case of unilateral FDI from North to the South, the regulator in the North may choose emission standard from a partition of reasonable ranges, say $z_n \in z_n \in [0, \theta_n) \cup [\theta_n, \theta_s]$. If $z_n \in [\theta_n, \theta_s]$, then there will be $e_{ss} = z_s$, $e_{sn} = z_n$, and $e_{nn} = \theta_n$. W_s^{EF} and W_n^{EF} are concave in z_s and z_n respectively, therefore according to the best response functions between z_s, z_n under constraints $0 \le z_s \le \theta_s$ and $\theta_n \le z_n \le \theta_s$, the equilibrium emission standards are

$$\left(z_s^*, z_n^*\right) = \begin{cases} \left(a + \frac{\theta_n}{2} - \frac{3\theta_s}{2}, \theta_n\right), & \text{if } \frac{3\theta_s}{2} - \frac{\theta_n}{2} < a < \frac{5\theta_s}{2} - \frac{\theta_n}{2}; \\ \left(\theta_s, \theta_n\right), & \text{if } a \ge \frac{5\theta_s}{2} - \frac{\theta_n}{2}. \end{cases} \tag{25}$$

If $z_n \in [0, \theta_n)$, then there will be $e_{ss} = z_s$, $e_{sn} = z_n$, and $e_{nn} = z_n$. Under these circumstances, W_s^{EF} and W_n^{EF} are also concave in z_s and z_n respectively. According 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 equilibrium of emission standards is

$$\left(z_s^*, z_n^*\right) = \begin{cases} \left(a + \frac{\theta_n}{2} - \frac{3\theta_s}{2}, 0\right), \text{ if } \frac{3\theta_s}{2} - \frac{\theta_n}{2} < a < \frac{5\theta_s}{2} - \frac{\theta_n}{2}; \\ (\theta_s, 0), \text{ if } a \geq \frac{5\theta_s}{2} - \frac{\theta_n}{2}. \end{cases} \tag{26}$$

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

$$\begin{aligned} &W_n^{EF} \mid_{(z_s^*, z_n^*) = \left(a + \frac{\theta_n}{2} - \frac{3\theta_s}{2}, \theta_n\right)} - W_n^{EF} \mid_{(z_s^*, z_n^*) = \left(a + \frac{\theta_n}{2} - \frac{3\theta_s}{2}, 0\right)} \\ &= -\frac{\theta_n}{6}\left(\theta_n + \theta_s\right) < 0; \end{aligned} \tag{27}$$

$$\begin{aligned} &W_n^{EF} \mid_{(z_s^*, z_n^*) = (\theta_s, \theta_n)} - W_n^{EF} \mid_{(z_s^*, z_n^*) = (\theta_s, 0)} \\ &= -\frac{\theta_n}{9}\left(a - \theta_s + 2\theta_n\right) < 0. \end{aligned} \tag{28}$$

Equations 27 and 28 clearly indicate that the northern regulator always chooses the most stringent emission standard, i.e., $z_n^* = 0$. This result implies that the environmental benefits and profits gained by the domestic firm as a result of implementing a stringent environmental policy outweigh the loss of consumer surplus, even though the foreign country can free-ride on the improvement in environment.

3.4 Bilateral FDI

When the two firms are engaged in FDI, the objective functions of the firms are then respectively,

$$\underset{\{q_s^s, q_s^n\}}{\text{Max}}\ \pi_s^{FF} = \left(a - q_s^s - q_n^s - c_s\left(e_{ss}\right)\right) q_s^s + \left(a - q_n^n - q_s^n - c_s\left(e_{sn}\right)\right) q_s^n - F, \tag{29}$$

$$\underset{\{q_n^n, q_n^s\}}{\text{Max}}\ \pi_n^{FF} = \left(a - q_n^n - q_s^n - c_n\left(e_{nn}\right)\right) q_n^n + \left(a - q_s^s - q_n^s - c_n\left(e_{ns}\right)\right) q_n^s - F. \tag{30}$$

where superscript FF stands for the case of bilateral FDI. The profits of southern and northern firms earned in foreign markets through FDI are $\left(a - q_n^n - q_s^n - c_s\left(e_{sn}\right)\right) q_s^n - F$ and $\left(a - q_s^s - q_n^s - c_n\left(e_{ns}\right)\right) q_n^s - F$ respectively. The global emissions level 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 southern and northern countries are, respectively

$$W_s^{FF} = \frac{Q_s^2}{2} + \pi_s^{FF} - D\left(q_s^{s*}e_{ss} + q_s^{n*}e_{sn} + q_n^{n*}e_{nn} + q_n^{s*}e_{ns}\right), \quad (31)$$

$$W_n^{FF} = \frac{Q_n^2}{2} + \pi_n^{FF} - D\left(q_s^{s*}e_{ss} + q_s^{n*}e_{sn} + q_n^{n*}e_{nn} + q_n^{s*}e_{ns}\right). \quad (32)$$

Notice that the firms' costs associated with products sold in the foreign market have become $c_s\,(e_{sn})$ and $c_n\,(e_{ns})$. This is because, following FDI, the new plant opened in the foreign country is subject to emission standards of the foreign government. Based on this fact, the emission levels of firms in each market can be characterized as $e_{ss} = z_s \le \theta_s, e_{sn} = z_n \le \theta_s, e_{nn} = \min\{\theta_n, z_n\}, e_{ns} = \min\{\theta_n, z_s\}$. Under this circumstance, the emission standard of one country will not affect the competitive dynamics in the other country in a Cournot model. Thus there is no interaction between emission standards in the two countries, and one country's decision on emission standard will not affect or be affected by the other country's decision.

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

First we discuss the emission standard determination in the South. Similar procedures apply. Consider first that $z_s \in [\theta_n, \theta_s]$, then $e_{ns} = \theta_n$ and $e_{ss} = z_s$. W_s^{FF} is concave in z_s. Therefore a welfare maximizing z_s^* can be obtained by the FOC as,

$$z_s^* = \min\{a - \theta_s + \theta_n, \theta_s\}. \quad (33)$$

Consider second that when $z_s \in [0, \theta_n)$, then $e_{ns} = e_{ss} = z_s$. In this case, W_s^{FF} is concave in z_s. Therefore a welfare maximizing z_s^* can be obtained by the FOC as,

$$z_s^* = 0. \quad (34)$$

A benevolent regulator compares the two standards and picks the globally optimal one. When $a < 2\theta_s - \theta_n$, $z_s^* = \min\{a - \theta_s + \theta_n, \theta_s\} = a - \theta_s + \theta_n$, we have

$$\begin{aligned} &W_s^{FF} \mid_{z_s^* = a - \theta_s + \theta_n} - W_s^{FF} \mid_{z_s^* = 0} \\ &= \frac{1}{6}\left(a^2 - 2\theta_s a - 2\theta_n\theta_s + \theta_s^2\right). \end{aligned} \quad (35)$$

According to (35), the emission standards in the South are

$$z_s^* = \begin{cases} 0, \text{ if } \theta_n < \theta_s \le \left(2+\sqrt{3}\right)\theta_n, \text{ or } \theta_s > \left(2+\sqrt{3}\right)\theta_n \text{ and } a \le \theta_s + \sqrt{2\theta_s\theta_n}; \\ a - \theta_s + \theta_n, \text{ if } \theta_s > \left(2+\sqrt{3}\right)\theta_n \text{ and } \theta_s + \sqrt{2\theta_s\theta_n} < a < 2\theta_s - \theta_n. \end{cases} \quad (36)$$

When $a \ge 2\theta_s - \theta_n$, and $z_s^* = \min\{a - \theta_s + \theta_n, \theta_s\} = \theta_s$, we have

$$\begin{aligned} &W_s^{FF} \mid_{z_s^* = \theta_s} - W_s^{FF} \mid_{z_s^* = 0} \\ &= \frac{1}{3}a\left(\theta_s - \theta_n\right) - \frac{1}{6}\left(3\theta_s^2 + \theta_n^2 - 2\theta_s\theta_n\right). \end{aligned} \quad (37)$$

In light of (37), the emission standards in the South are

$$z_s^* = \begin{cases} 0, \text{ if } \theta_n < \theta_s \le \left(2+\sqrt{3}\right)\theta_n \text{ and } 2\theta_s - \theta_n < a < \frac{\left(3\theta_s^2+\theta_n^2-2\theta_s\theta_n\right)}{2(\theta_s-\theta_n)}; \\ \theta_s, \text{ if } \theta_n < \theta_s \le \left(2+\sqrt{3}\right)\theta_n \text{ and } a \ge \frac{\left(3\theta_s^2+\theta_n^2-2\theta_s\theta_n\right)}{2(\theta_s-\theta_n)}, \text{ or } \theta_s > \left(2+\sqrt{3}\right)\theta_n. \end{cases} \tag{38}$$

(36) and (38) show that if the market size of the South is small enough, then the South imposes the most stringent environmental policy, i.e., $z_s^* = 0$. When the South has a small market, the benefits from the improvements in the environment outweighs the loss from consumer surplus. The southern regulator then has an incentive to impose a more stringent environmental standard even though some of the benefit from abatement accrues to the other country as pollution is transboundary.

Since FDI is bilateral in this subsection, we discuss the emission standard determination for the North as well. Notice that for $z_n \in [\theta_n, \theta_s]$, then $e_{nn} = \theta_n$ and $e_{sn} = z_n$. W_n^{FF} is concave in z_n, and the FOC yields

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

For the other range, i.e., $z_n \in [0, \theta_n]$, we have $e_{nn} = e_{sn} = z_n$. W_n^{FF} is concave in z_n and the FOC yields

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

To determine which standard the northern government will choose, just compare the social welfare of the country under these standards.

When $\theta_s \ge 3\theta_n$, $z_n^* = \min\left\{\frac{(\theta_s-\theta_n)}{2}, \theta_n\right\} = \theta_n$. Therefore the regulator always sets $z_n^* = \theta_n$.

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

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

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

3.5 The impact of FDI on emission standard

To better understand PHH and its relation with environmental policies, we need to characterize the changes in environmental standards in the wake of FDI liberalization. Existing empirical work generally generated mixed results with respect to the impact of FDI as a driving force in the "race to the bottom" and/or "pollution haven" phenomenon. This article considers the PHH, race-to-the-bottom, race-to-the-top effect, and

Table 1 Equilibria of emission standard with $\theta_n < \theta_s < \frac{3}{2}\theta_n$ and $2\theta_s - \theta_n < a < 2\theta_n$

	(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

regulatory chill phenomena in a general reciprocal trade and FDI setting. We show that a "race to the top" may also arise in equilibrium.

In the rest of this subsection, let the combinations of FDI and Ex denote specific FDI–export scenarios. The left term inside the parentheses stands for the strategy of the northern firm, and the right term stands for that of the southern firm. For instance, (FDI, Ex) denotes the case in which the northern firm is the source of FDI and the southern firm exports.

Table 1 depicts the equilibria of emission standards under different FDI–export scenarios under the assumption that the technological gap between the North and the South is small and that market sizes are also relatively small.

In Table 1, it can be observed that in the (Ex, Ex) case, because $\theta_n < \theta_s$, $z_n^* = a + \theta_n - 2\theta_s < z_s^* = a + \frac{\theta_n}{2} - \frac{3\theta_s}{2}$, which implies that the North sets a more stringent emission standard than the South. Under (FDI, Ex) and (Ex, FDI), the host countries for FDI set their emission standards at 0, the most stringent form.

When countries move from export only to at least one country conducting FDI, the FDI host country[7] may tighten its environmental standard from some positive amount to the most stringent form, so-called "race-to-the-top". The condition that ensures "race-to-the-top" is obtained through equilibrium z_s and z_n in all four subsections of Sect. 3. Formally, for race-to-the-top to arise in equilibrium, the following conditions must be satisfied:

$$\begin{cases} \text{if } \theta_n \le \theta_s < \frac{3}{2}\theta_n, \text{ and } 2\theta_s - \theta_n < a < 4\theta_s - 2\theta_n \text{ or } a > \frac{(\theta_s^2 + 3\theta_n^2 - 2\theta_s\theta_n)}{2(2\theta_s - 3\theta_n)}; \\ \text{or } \frac{3}{2}\theta_n < \theta_s \le \frac{3+\sqrt{3}}{3}\theta_n, \text{ and } 2\theta_s - \theta_n < a < \frac{(\theta_s^2 + 3\theta_n^2 - 2\theta_s\theta_n)}{2(2\theta_s - 3\theta_n)}; \\ \text{or } \frac{3+\sqrt{3}}{3}\theta_n < \theta_s < \frac{5+\sqrt{10}}{5}\theta_n, \text{ and } 2\theta_s - \theta_n < a < 4\theta_s - 2\theta_n; \\ \text{or } \frac{5+\sqrt{10}}{5}\theta_n \le \theta_s \le \left(2+\sqrt{3}\right)\theta_n, \text{ and } 2\theta_s - \theta_n < a < \frac{(3\theta_s^2 + \theta_n^2 - 2\theta_s\theta_n)}{2(\theta_s - \theta_n)}, \end{cases} \tag{41}$$

Table 1 is one illustration for a subset of conditions listed in (39). This result is summarized in the proposition below whose proof is omitted.

Proposition 2 *Under conditions* (41)*, the liberalization of FDI strengthens the emission standard of the host country of the FDI, making the environmental policy of the host country more stringent, resulting a "race-to-the-top" phenomenon.*

When a host country for FDI considers whether to amend its emission standards, it takes into account the impact of standard change on consumer surplus, the profits of the domestic firm and environment quality. When markets are small, the improvement

[7] Or both countries in the case of bilateral FDI.

Table 2 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 environment quality outweighs the loss of consumer surplus and the profits made by the domestic firm. Therefore, the host country receiving FDI chooses to raise its emission standards.

As clarified at the beginning of this section, the results of this model are not one sided. Table 2 below offers a different case.

In Table 2, the technology gap between the northern and southern countries is moderate, i.e., $2\theta_n < \theta_s < 3\theta_n$, and the market size of countries is large enough, i.e., $4\theta_s - 2\theta_n < a$. When changing from (Ex, Ex) to (FDI, Ex), the host country receiving FDI, the South, holds its emission standards at θ_s; when changing from (Ex, Ex) to (FDI, FDI) , the South still holds its emission standard at θ_s. This interesting result can be formally expressed in the following proposition.

Proposition 3 *When the technology gap between the northern and southern countries is moderate, i.e.,* $2\theta_n < \theta_s < 3\theta_n$*, and the market sizes of these countries are large enough, i.e.,* $4\theta_s - 2\theta_n < a$*, FDI liberalization does not have an upward impact on the host country's emission standards; they remain in their laxest form, which represents the "regulatory chill" case.*

When the market is large and the technological gap is moderate, the South is reluctant to amend its environmental standard from the laxest form. This is because the southern firm is efficient enough to compete with the northern firm in the domestic market but inefficient to (indirectly) drag the environmental standards down to the lowest level. In Table 2, the South displays the kind of loosest form of emission standard. Under that condition, if it raises its environmental standards, the loss of consumer surplus and the profits of the domestic firms cannot be compensated by the increase in environment quality. Thus the South prefers to keep its emission standards intact.

4 FDI equilibrium

In the preceding sections, the equilibria of emission standards set by governments in various FDI–export scenarios are discussed. Based on those results, the article models the game that firms interactively make decisions on FDI. The strategic form of this FDI–export game is shown in Fig. 1.

In this simple game, a firm strategically decides whether to conduct FDI, not only considering whether it can reap higher profits under FDI than under export in the foreign market, but also taking into account the impact of its decision on its profits in the domestic market. In the case of FDI, the increase in firms' foreign profits more than offsets the loss of domestic profits. Thus FDI will be preferred.

Fig. 1 FDI–export game

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

When $\theta_n < \theta_s < \frac{3}{2}\theta_n$ and $2\theta_s - \theta_n < a < 2\theta_n$, we have

$$\pi_n^{FE} - \pi_n^{EE} = \frac{a^2}{9} + \frac{20a\theta_s}{9} - \frac{22a\theta_n}{9} - \frac{41{\theta_s}^2}{36} + \frac{\theta_n\theta_s}{18} + \frac{43{\theta_n}^2}{36} - F, \quad (42)$$

$$\pi_n^{FF} - \pi_n^{EF} = \frac{a^2}{9} - \frac{5a\theta_n}{9} + \frac{a\theta_s}{3} + \frac{4{\theta_n}^2}{9} - \frac{\theta_n\theta_s}{3} - F, \quad (43)$$

$$\pi_s^{EF} - \pi_s^{EE} = \frac{a^2}{9} - \frac{4a\theta_s}{9} + \frac{2a\theta_n}{9} + \frac{4{\theta_s}^2}{9} - \frac{4\theta_n\theta_s}{9} + \frac{{\theta_n}^2}{9} - F, \quad (44)$$

$$\pi_s^{FF} - \pi_s^{FE} = \frac{a^2}{9} + \frac{a\theta_n}{9} - \frac{a\theta_s}{3} + \frac{{\theta_n}^2}{36} - \frac{\theta_n\theta_s}{6} + \frac{{\theta_s}^2}{4} - F. \quad (45)$$

To simplify notations, let $\pi_n^{FE} - \pi_n^{EE} = F_1 - F$, $\pi_n^{FF} - \pi_n^{EF} = F_2 - F$, $\pi_s^{EF} - \pi_s^{EE} = F_3 - F$ 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 the fixed cost of establishing a new subsidiary plant abroad,*

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

Proof The first step is to compare F_1, F_2, F_3 and F_4 with each other. Since $a > \theta_s > \theta_n$, thus $F_1 - F_2 = \frac{(\theta_s - \theta_n)}{36}(68a - 41\theta_s - 27\theta_n) > 0$; $F_2 - F_3 = \frac{(\theta_s - \theta_n)}{9}(7a - 4\theta_s - 3\theta_n) > 0$; $F_3 - F_4 = \frac{(\theta_s - \theta_n)}{12}(8a - 3\theta_s - 5\theta_n) > 0$, and $F_4 = \frac{1}{36}(2a + \theta_n - 3\theta_s)^2 > 0$.

When $F > F_1$, export is the dominant strategy for both firms, so the equilibrium entails no FDI in this case. When $F_1 > F > F_2$, 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, but from the North to the South. When $F_2 > F > F_4$, the equilibrium is also unilateral FDI from the North to the South. When $F_4 > F > 0$, the equilibrium is bilateral FDI. □

The results here are typical extensions of the proximity–concentration framework of FDI. In the current article, it is shown that unilateral FDI from the South to the North is never a Nash equilibrium. This is simply because of the competitive disadvantage in technology of the southern firm.

5 Concluding remarks

This article studies the interrelationship between FDI and environmental policy using a North–South model in a market share game. The policy instrument considered in the model is a conventional CAC one—emission standard regulation—and does not generate any fiscal revenues for the government. Thus it induces no incentive distortion on regulators' environmental policy decisions.

The trade cost in the current article is endogenously determined tariff, the melting-iceberg trade cost. Greenfield FDI is allowed as a substitute for exports. Firms compete *à la* Cournot subject to each country's domestic environmental standard. Pollution is perfectly transboundary and is hence a global public bad. Emissions are only accompanied by production. Unlike previous models that use a political economy framework or third country market settings, this article considers a two-country reciprocal trade and FDI model that appears to be very general.

An important finding of this article is that whether FDI will make countries' environmental policies more stringent or more lax may depend on the technology gap and more importantly, market size of the trading countries. In this model, we find that if the South is experiencing only a small lag in technology and if both markets are small, the host country receiving the FDI may raise its emission standard upon FDI liberalization, causing a "race to the top" effect. If countries' technology gaps are moderate and market sizes are sufficiently large, then the South is reluctant to tighten its emission standard, i.e., the "regulatory chill" hypothesis may hold. Although our model is a North–South model that is still far away from resembling the actual complex web of the world's trading system and FDI flows, it does indicate the importance of climate negotiations between large trading nations, such as the US and China. Furthermore, we conjecture that the model may be extended to a n-party setting to suggest that climate change negotiations may be primarily conducted among large economies.

As a usual exercise, FDI and export as alternative strategies to serve foreign markets are characterized. Conditions under which that both countries choose to export, those that encourage unilateral FDI from North to South, and those that facilitate bilateral FDI in equilibrium are given.

The limitation of the model is that it does not consider employment and growth concerns[8], the spillover of technology and R&D, and other similar concerns that represent some important dimensions of the interrelationship between FDI and environment policies. Future research might investigate whether and how these factors affect environmental policies in response to FDI inflows, preferably in a dynamic setting.

[8] The static nature of the current model makes it poorly suited to addressing dynamic issues like growth. As for the job creation effect of FDI, it usually does not have impact on the relationship between FDI and carbon emission. Statistics show that the unemployment rate is higher in developed countries and the growth rate is higher in developing countries in recent decades. Incentives for job creation and short-term growth through FDI inflows in FDI receiving countries (mainly developing countries) might be diminishing. Instead, FDI motivated by carbon emissions became one of the top concerns for the policymakers in the developing world.

6 Appendix A

Proof of Proposition 1 Since firms only produce goods in their home countries and set emission levels according to domestic emission standards, it must be $e_{ss} = z_s \le \theta_s$, and $e_{nn} = z_n \le \theta_n$. Substituting (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 derived from (7), (8) under constraints $z_s \le \theta_s$ and $z_n \le \theta_n$, the equilibrium of emission standard should be

$$\left(z_s^*, z_n^*\right) = \begin{cases} (a - \theta_n, a - \theta_s), \text{ if } \theta_s < a < \theta_s + \theta_n; \\ (\theta_s, \theta_n), \text{ if } a \ge \theta_s + \theta_n. \end{cases} \tag{46}$$

Substituting (46) and (9), into (4), one sees that the optimal quantity of the southern firm's exports 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 that in equilibrium, $q_s^{n*} = 0$;

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

When $a > 4\theta_s - 2\theta_n$, $q_s^{n*} = \frac{a-(4\theta_s-2\theta_n)}{9} > 0$. □

7 Appendix B

According to the objective functions of northern and southern firms in Sect. 3.2, the optimal production level of every firm in each market can be solved as

$$q_s^{s*} = \frac{a - 2c_s(e_{ss}) + c_n(e_{ns})}{3}, \tag{47}$$

$$q_s^{n*} = \frac{a - 2c_s(e_{ss}) + c_n(e_{nn}) - 2T_n}{3}, \tag{48}$$

$$q_n^{n*} = \frac{a - 2c_n(e_{nn}) + c_s(e_{ss}) + T_n}{3}, \tag{49}$$

$$q_n^{s*} = \frac{a - 2c_n(e_{ns}) + c_s(e_{ss})}{3}. \tag{50}$$

In this FDI–export scenario, the global emissions level is $E^{FE} = \left(q_s^{s*} + q_s^{n*}\right)e_{ss} + q_n^{s*}e_{ns} + q_n^{n*}e_{nn}$, so the expressions of social welfare are

$$W_s^{FE} = \frac{Q_s^2}{2} + \pi_s^{FE} - D\left(\left(q_s^{s*} + q_s^{n*}\right)e_{ss} + q_n^{s*}e_{ns} + q_n^{n*}e_{nn}\right), \tag{51}$$

$$W_n^{FE} = \frac{Q_n^2}{2} + \pi_n^{FE} + T_n q_s^{n*} - D\left(\left(q_s^{s*} + q_s^{n*}\right)e_{ss} + q_n^{s*}e_{ns} + q_n^{n*}e_{nn}\right). \tag{52}$$

Substituting (49), (48) into (52), and maximizing W_n^{FE} w.r.t T_n, we obtain the optimal tariff

$$T_n^* = \frac{a - c_s(e_{ss}) - e_{nn} + 2e_{ss}}{3}. \quad (53)$$

Substituting (53) into (48), we can obtain

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

Since $e_{ss} = z_s \leq \theta_s$ and $e_{nn} = z_n \leq \theta_n$, the equilibrium of emission standards in the North is

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

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

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