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Bouwe R. Dijkstra
University of Nottingham

Anuj J. Mathew
Universidad de Navarra

Arijit Mukherjeea
University of Nottingham

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ABSTRACT

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Bouwe R. Dijkstra
School of Economics, University of Nottingham
NG7 2RD, UK
bouwe.dijkstra@nottingham.ac.uk

Anuj J. Mathew
Universidad de Navarra
Campus Universitario
31080 Pamplona
amathew@unav.es

Arijit Mukherjeea
School of Economics, University of Nottingham
NG7 2RD, UK
arijit.mukherjee@nottingham.ac.uk

Strict environmental policy: An incentive for FDI

Bouwe R. Dijkstra[a,*], Anuj J. Mathew[b] and Arijit Mukherjee[a]

[a]School of Economics and GEP, University of Nottingham, UK

[b]School of Economics, University of Navarra, Pamplona, Spain

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Abstract

Empirical evidence has so far failed to confirm that lenient environmental regulation attracts investment from polluting firms. We show that a firm may want to relocate to a country with stricter environmental regulation, when the move raises its rival's cost by sufficiently more than its own. We model a Cournot duopoly with a foreign and an incumbent domestic firm. When the foreign firm moves to the home country, the domestic government will respond by increasing the environmental tax rate. This may hurt the domestic firm more than the foreign firm. The home (foreign) country's welfare is (usually) lower with FDI.

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*Corresponding author. School of Economics, University of Nottingham, Nottingham NG7 2RD, UK. Tel. +44 115 8467205, fax +44 115 9514159, email bouwe.dijkstra@nottingham.ac.uk.

1 Introduction

While stimulating economic growth and development, Foreign Direct Investment (FDI) has also been considered as an important source of environmental degradation in its host region. This has fuelled concerns whether it is sustainable in the long run to attain economic growth and development through FDI at the expense of environmental quality. To address this concern, it is important to question whether multinationals will prefer to invest in regions with more lenient environmental regulation.

The Pollution Haven Hypothesis (PHH) states that polluting capital will move to countries with lenient environmental regulation. The empirical literature on the PHH has been inconclusive. Low and Yeates (1992), Kolstad and Xing (2001), List and Co (2000), Becker and Henderson (2000), Keller and Levinson (2002), Kahn (1997), List et al. (2003), Cole and Elliott (2005) as well as several papers analyzed by Jeppesen et al. (2001) found strong evidence in favor of the PHH. Eskeland and Harrison (2003), and Javorcik and Wei (2004) however concluded that environmental regulation does not influence the location decision of an industry. Indeed, McConnell and Schwab (1990), Duffy-Deno (1992), Friedman et al. (1992) and Levinson (1996) found that environmental regulation had no significant, and sometimes even a positive, effect on investment. Dean et al. (2009) found mixed evidence for and against the PHH.

We propose a new explanation for the mixed empirical evidence regarding the PHH and especially the finding that strict environmental policy seems to attract FDI. The empirical models may have been miss-specified in assuming that the governments set environmental policy before firms decide on FDI and thus environmental policy affects FDI. Instead, it could be that the firms move before the governments and thus FDI influences environmental policy. In our model, a foreign firm may prefer to move to the home country even though the home government will respond to this by making its environmental policy stricter than before and indeed stricter than in the foreign country. Although

FDI increases the foreign firm's costs, it raises its domestic rival's costs even more. To our knowledge, we are the first to propose raising rival's cost (Salop and Scheffman, 1983, 1987) as a motive for FDI.

There are some papers that model a firm's attempts to take advantage of environmental policy to raise its rival's cost, other than through FDI[1]. Sartzetakis (1997) models a tradable emission permit market in a duopoly with a leader and a follower. The leader may set a high permit price in order to raise the follower's cost. Puller (2006) shows that a firm has an incentive to innovate so that the regulator will set a stricter standard, which imposes high costs on its rivals.

While, as discussed above, most empirical papers have assumed that environmental policy affects FDI, Cole et al. (2006) examine the effect of FDI on environmental policy. They find that FDI leads to stricter environmental policy when the government is mostly interested in social welfare (as we predict in our paper), but to more lenient environmental policy when the government is very corrupt.

Ulph and Valentini (2001 and Petrakis and Xepapadeas (2003) compare the games where the governments set their policies before and after the firms make their location decisions. Petrakis and Xepapadeas (2003) analyze environmental taxation for a monopolist that can relocate abroad, with foreign environmental policy exogenously given. Ulph and Valentini's (2001) two-country, two-firm model differs from ours in that they assume that the firms are completely mobile at the outset of the game and all of the firm's profits accrue to the host country. We assume that all of the profits of the home (foreign) firm accrue to the home (foreign) country, and only the foreign firm can relocate. Ulph and Valentini (2001) take absolute emission limits as the instrument of environmental policy, whereas in our model we look at environmental taxation as an instrument of environment policy.

[1] In different settings, Oster (1982) and Michaelis (1994) also analyze a firm's actions that raise its rival's costs more than its own costs. However, unlike the present paper, they do not model the way in which the firm's action leads to differential cost increases.

De Santis and Stähler (2009) look at the case of bilateral FDI with identical firms and countries, where firms undertake FDI to avoid the transportation costs. We explicitly rule out this traditional motive by setting the foreign firm's marginal costs under exporting lower than with FDI. In our paper, the motive for FDI is that relocation leads to a higher increase in the environmental tax rate for the home firm than for the foreign firm itself. This motive is absent in De Santis and Stähler (2009), because the two firms face the same tax rates when they are located in their own countries, and therefore also the same tax increase with FDI.

The remainder of the paper is structured as follows. Section 2 introduces the basic model structure. Section 3 introduces the Cournot model with subsection 3.1 discusses the game under both export and FDI scenarios and subsection 3.2 identifies the conditions under which it would be profitable for the foreign firm to do FDI. In subsection 3.3 we look at the special case of equal production costs. In Section 3.4 we compare the countries' welfare under export and FDI.

Section 4 introduces the Bertrand model with the subsection discusses the game under both export and FDI scenarios and subsection 4.2 identifies the conditions under which it would be profitable for the foreign firm to do FDI. In subsection 4.3 we look at the special case of equal production costs.

Under both the cournot and Bertrand models, we will establish the range of parameter values for which the foreign firm prefers FDI, although it entails higher costs. Section 5 provides some concluding remarks and scope for future research.

2 Basic Model

Consider a duopoly with one firm f initially located in the foreign country f and the other firm h located in the home country h. Firm f has the option to relocate all of its production to country h, where all the consumers live. There is a fixed cost F of relocation.[2] The marginal cost of production of the domestic firm is constant and equal to c_h while the marginal cost of production of the foreign firm is constant and equal to c_f^x under exports (where c_f^x also includes the transportation cost) and c_f^R under FDI.[3]

We assume that:

$$c_f^R \geq c_f^x. \tag{1}$$

i.e the foreign firm's marginal cost of production is higher with FDI than with exporting. As a result, it would not be profitable for the foreign firm to undertake FDI in the absence of environmental regulation. We make this assumption to ensure that environmental policy is the only reason for the foreign firm to undertake FDI.

Pollution is a by-product of the production process. There is no technology available to reduce emissions per unit of output. In scenario s, where $s = R, x$, firm i, where $i \in h, f$, has output q_i^s and emissions eq_i^s. Without loss of generality, we normalize the emissions-to-output ratio e to one. Thus total emissions E are then, for the home and foreign country, respectively:

$$\begin{aligned} \text{with export:} \quad & E_h^x = q_h^x \;\&\; E_f^x = q_f^x, \\ \text{and with FDI} \quad : \quad & E_h^R = q_h^R + q_f^R \;\&\; E_f^R = 0. \end{aligned}$$

Environmental damage D_i occurs only in the country i where the emissions take place, according to:

$$D_i\left(E_i\right) = \lambda_i E_i^2,$$

where λ_i is the environmental damage coefficient. The environmental damage coefficient could differ from one country to another, because one country's ecosystems are more vulnerable to pollution than another's, or one country's citizens or government care more about environmental damage than the other's.

[2] F captures all the start-up costs of a new plant, including the adjustment cost of learning to operate in a new institutional and financial environment.

[3] Subscripts $i, i = f, h$, refer to the foreign and home firm or country, respectively. Superscripts $s, s = x, R$ refer to the scenario where the foreign firm is exporting and relocating, respectively.

Marginal damage MD_i is then given by:

$$MD_i = 2\lambda_i E_i. \tag{2}$$

Environmental policy in country i, $i = f, h$, under scenario s, $s = x, R$, consists of a tax t_i^s per unit of emissions. Since firms cannot reduce their emissions per unit of output, the environmental tax is effectively on output.

In addition to (1), we impose a condition on the parameters such that:[4]

$$t_h^R + c_f^R > t_f^x + c_f^x, \tag{3}$$

i.e. full marginal costs (including production and transport costs as well as environmental taxation) are higher with FDI than with exports.The game between the firms and the governments takes place in a perfect-information setting[5] and consists of three stages. In the first stage, firm f decides whether to export or to undertake FDI. In stage two, the governments set the environmental tax rate that maximizes their country's welfare. In the final stage, the two firms set their output levels.

3 The Cournot model

Under the Cournot duopoly we assume that both the firms produce a homogenous good and the firms face a linear market demand:

$$P = A - q_h^s - q_f^s,$$

with $A > 0$, P the product price and q_i^s the output by firm i,where $i \in h, f$, in scenario s, where $s = x, R$. Define for simplicity:

$$a_f^x = A - c_f^x > 0 \qquad a_f^R = A - c_f^R > 0 \qquad a_h = A - c_h > 0. \tag{4}$$

Assumption (1) can then be written as:

$$a_f^R \leq a_f^x. \tag{5}$$

[4] We will present the condition in terms of the exogenous parameters as (26) in subsection 3.1.2, after having solved for t_h^R and t_f^x.

[5] See Bommer (1999) for a firm's incentive to relocate under asymmetric information.

Using (5), this can be rewritten as:

$$t_h^R - a_f^R > t_f^x - a_f^x. \tag{6}$$

We impose this condition to make sure that the foreign firm does not relocate in order to take advantage of lower costs in the home country.

3.1 Government Policy

In this section we analyze the second and third stage of the game. In stage two, the governments decide on their environmental policies and in stage three the firms set their output levels. In subsection 3.1.1 (3.1.2), we analyze the sub-game where the foreign firm has decided to export (undertake FDI).

3.1.1 Foreign firm exports

In this sub-game the foreign firm has decided, in stage one, to export. We start our analysis in stage three, where the two firms i, $i = f, h$, set the output levels that maximize their profits Π_i^x . The maximization problem for firm i, $i = f, h$, is:[6]

$$\max_{q_i^x} \Pi_i^x = \left(a_i^x - q_i^x - q_{-i}^x - t_i^x\right) q_i^x, \tag{7}$$

with $a_h^x = a_h$. Solving the first order conditions for the profit-maximizing output levels as a function of the tax rates yields:

$$q_i^x = \frac{2\left(a_i^x - t_i^x\right) - \left(a_{-i}^x - t_{-i}^x\right)}{3}. \tag{8}$$

Substituting (8) into the profit functions (7) yields:

$$\Pi_i^x = \left[\frac{2\left(a_i^x - t_i^x\right) - \left(a_{-i}^x - t_{-i}^x\right)}{3}\right]^2. \tag{9}$$

In stage two, the home and foreign governments set the environmental tax rates that maximize social welfare. Social welfare Wi in country i ($i = h, f$) is the sum of firm i's profit, consumer surplus (for the home country) and environmental tax revenue, minus environmental damage.

[6] The second order conditions for all maximization problems in this chapter are satisfied.

The foreign government maximizes:

$$W_f^x = \Pi_f^x + t_f^x q_f^x - \lambda_f \left(q_f^x\right)^2, \tag{10}$$

with Π_f^x given by (9) and q_f^x given by (8). Differentiating and solving for t_f^x , we get:

$$t_f^x = \frac{(4\lambda_f - 1)\left(2a_f^x - a_h + t_h^x\right)}{4(2\lambda_f + 1)}. \tag{11}$$

Similarly the home government maximizes:

$$W_h^x = \Pi_h^x + \frac{1}{2}\left(q_h^x + q_f^x\right)^2 + t_h^x q_h^x - \lambda_h \left(q_h^x\right)^2, \tag{12}$$

with Π_h^x given by (9) and q_h^x given by (8). Differentiating and solving for t_h^x , we get:

$$t_h^x = \frac{a_h(8\lambda_h - 3) + 4\lambda_h\left(t_f^x - a_f^x\right)}{3 + 8\lambda_h}. \tag{13}$$

Substituting (11) into (13) and solving for t_h^x we get:

$$t_h^x = \frac{a_h(3\lambda_h + 4\lambda_h\lambda_f - 1 - 2\lambda_f) - 2\lambda_h a_f^x}{1 + 2\lambda_f + 3\lambda_h + 4\lambda_f\lambda_h}. \tag{14}$$

Substituting (14) into (11) and solving for t_f^x we get:

$$t_f^x = \frac{(4\lambda_f - 1)\left(2a_f^x\lambda_h + a_f^x - a_h\right)}{2(1 + 2\lambda_f + 3\lambda_h + 4\lambda_f\lambda_h)}. \tag{15}$$

Substituting (14) and (15) into (8), we find the equilibrium output levels as:

$$q_h^x = \frac{3a_h + 4\lambda_f a_h - a_f^x}{2(1 + 2\lambda_f + 3\lambda_h + 4\lambda_f\lambda_h)}, \quad q_f^x = \frac{2\lambda_h a_f^x + a_f^x - a_h}{1 + 2\lambda_f + 3\lambda_h + 4\lambda_f\lambda_h}. \tag{16}$$

The conditions for q_h^x and q_f^x to be positive are, respectively:

$$\lambda_f > \frac{a_f^x - 3a_h}{4a_h}, \quad \lambda_h > \frac{a_h - 3a_f^x}{2a_f^x}. \tag{17}$$

We wish to restrict our analysis to the case where the environmental problem is serious enough to warrant a positive environmental tax. From (14), we see that $t_h^x > 0$ if and only if:

$$\lambda_h > \frac{a_h(1 + 2\lambda_f)}{3a_h + 4a_h\lambda_f - 2a_f^x}. \tag{18}$$

As for the foreign country's tax rate, the second term in the brackets of the numerator on the R.H.S of (15) is positive by (17). Thus $t_f^x > 0$ if and only if:

$$\lambda_f > \frac{1}{4}. \tag{19}$$

Using (2) and (16), the environmental tax rate (14) in the home country can be rewritten as:

$$t_h^x = MD_h^x - \frac{\lambda_h a_f^x + a_h (1 + 2\lambda_f)}{1 + 2\lambda_f + 3\lambda_h + 4\lambda_f \lambda_h}.$$

Thus the environmental tax rate is lower than the marginal damage from pollution. There are two reasons for this. First, the government wants to correct the competitive distortion created by the duopoly (the domestic correction incentive as pointed out by De Santis and Stähler, 2006). Secondly, the home government wants to shift the profit from the foreign firm to the domestic firm (the profit-shifting incentive as pointed out by Brander and Spencer, 1985).[7]

By (2) and (16), the foreign country's environmental tax rate (15) too can be rewritten as:

$$t_f^x = \left(1 - \frac{1}{4\lambda_f}\right) MD_f^x.$$

In the foreign country as well, the environmental tax rate is below marginal damage. This is the result of the profit-shifting strategic incentive for the foreign government.

Substituting (16), (14) and (15) into the profit function (7), we get the profits of both firms when the foreign firm is exporting:

$$\Pi_h^x = \left[\frac{3a_h + 4\lambda_f a_h - a_f^x}{2(1 + 2\lambda_f + 3\lambda_h + 4\lambda_f \lambda_h)}\right]^2, \ \Pi_f^x = \left[\frac{2\lambda_h a_f^x + a_f^x - a_h}{1 + 2\lambda_f + 3\lambda_h + 4\lambda_f \lambda_h}\right]^2. \tag{20}$$

3.1.2 Foreign firm has undertaken FDI

In this sub-game the foreign firm has decided, in stage one, to relocate its plant to the home country. In stage three, each firm sets the output level that maximizes its profits.

[7] Bayındır-Upmann (2003) uses a slightly different classification into terms-of-trade and imperfect-competition effects. For the political-support effect in the presence of industry lobbies, see Schleich and Orden (2000).

The maximization problem for firm i, $i = f, h$, is:

$$\max_{q_i^R} \Pi_i^R = \left(a_i^R - q_i^R - q_{-i}^R - t_h^R\right) q_i^R - F_i, \tag{21}$$

with $a_h^R = a_h$ and fixed cost $F_f = F, F_h = 0$.The first order condition gives profit maximising output as

$$q_i^R = \frac{2a_i^R - a_{-i} - t_h^R}{3}. \tag{22}$$

Substituting this into the profit function (21) of the firms gives us the equilibrium levels of profit as:

$$\Pi_i^R = \left[\frac{2a_i^R - a_{-i} - t_h^R}{3}\right]^2 - F_i. \tag{23}$$

In stage two of the game, the home government sets the welfare maximising environmental tax rate:

$$\max_{t_h^R} W_h = \Pi_h^R + \frac{1}{2}\left(q_h^R + q_f^R\right)^2 + t_h^R\left(q_h^R + q_f^R\right) - \lambda_h\left(q_h^R + q_f^R\right)^2. \tag{24}$$

with Π_h^R given by (23) and q_h^R and q_f^R by (22). Taking the first order condition and simplifying for t_h^R, we get:

$$t_h^R = \frac{a_h\left(4\lambda_h - 3\right) + a_f^R\left(3 + 4\lambda_h\right)}{8\lambda_h + 6}. \tag{25}$$

Using (15) and (25) where t_f^x and t_h^R are solved for, we can rewrite condition (6) in terms of the exogenous parameters as:

$$\lambda_f < \frac{3a_h\left(4\lambda_h^2 - 3\lambda_h - 2\right) - \left(4\lambda_h + 3\right)\left[a_f^R\left(3\lambda_h + 1\right) - a_f^x\left(8\lambda_h + 3\right)\right]}{2\left[a_f^R\left(4\lambda_h + 3\right)\left(2\lambda_h + 1\right) - a_h\left(3 + 6\lambda_h + 8\lambda_h^2\right)\right]}. \tag{26}$$

Substituting the environmental tax rate (25) into the output levels of the firms (22) yields the profit maximizing output levels as follows:

$$q_f^R = \frac{a_f^R\left(3 + 4\lambda_h\right) - a_h\left(1 + 4\lambda_h\right)}{6 + 8\lambda_h},\ q_h^R = \frac{a_h\left(5 + 4\lambda_h\right) - a_f^R\left(3 + 4\lambda_h\right)}{6 + 8\lambda_h}. \tag{27}$$

We see that $q_f^R > 0$ always holds for $a_f^R \geq a_h$. It also holds for $a_f^R < a_h$when:

$$\lambda_h < \frac{3a_f^R - a_h}{4\left(a_h - a_f^R\right)}. \tag{28}$$

Similarly from (27), $q_h^R > 0$ always holds for $a_h \geq a_f^R$.It also holds for $a_h < a_f^R$ when:

$$\lambda_h < \frac{5a_h - 3a_f^R}{4\left(a_f^R - a_h\right)}. \tag{29}$$

Using (2) and (27), the home country's environmental tax rate can be rewritten as:

$$t_h^R = \frac{a_f^R - a_h}{2} + MD_h^R.$$

As before, the domestic correction incentive leads the government to lower the tax rate below marginal damage. On the other hand, the profit-shifting incentive now calls for a higher tax rate than when the foreign firm is located in the foreign country. When the two firms' production costs are the same, the two incentives cancel each other out and the environmental tax rate is equal to the marginal environmental damage (De Santis and Stähler, 2006). However, if the foreign firm is more productive than the home firm, the profit-shifting incentive dominates the domestic correction incentive and the tax rate is above marginal damage. The reverse occurs if the home firm is more productive.

On comparing the home environmental tax rates under export and when the foreign firm does FDI, we see that:[8]

Lemma 1: *The home country's environmental tax rate is higher when the foreign firm relocates its plant to the home country than when it exports, i.e.*

$$t_h^R > t_h^x.$$

The home country will set a higher tax rate under FDI, because there are now two firms on its territory rather than one. Pollution in the home country will be worse under FDI than under export by the foreign firm, since, under FDI, both the home and foreign firms produce and pollutes in the home country, whereas, under export, only the home firm pollutes in the home country. Therefore, the environmental tax rate has to increase in order to protect the environment.

[8] The proof is in Appendix A.

Finally, the two firms' profits are, substituting (25) into (23):

$$\Pi_f^R = \left[\frac{a_f^R\left(3+4\lambda_h\right)-a_h\left(1+4\lambda_h\right)}{6+8\lambda_h}\right]^2 - F \;\&\; \Pi_h^R = \left[\frac{a_h\left(5+4\lambda_h\right)-a_f^R\left(3+4\lambda_h\right)}{6+8\lambda_h}\right]^2. \tag{30}$$

3.2 Export or FDI?

Having analyzed the second (government policy) and third (firms' output) stages of the game in the previous section, we now move to stage one where the foreign firm decides between exporting and undertaking FDI. The foreign firm prefers FDI to exports if $\Pi_f^R > \Pi_f^x$.

Comparing the foreign firm's profits (20) under export and (30) under FDI, we find:

Lemma 2: *The foreign firm prefers FDI to exporting if and only if its fixed cost of relocation F is below $\hat{F}$, where*

$$\hat{F} \equiv \left[\frac{a_f^R\left(3+4\lambda_h\right)-a_h\left(1+4\lambda_h\right)}{6+8\lambda_h}\right]^2 - \left[\frac{2\lambda_h a_f^x + a_f^x - a_h}{1+2\lambda_f+3\lambda_h+4\lambda_f\lambda_h}\right]^2.$$

$\hat{F}$ may be negative, which means that profits under exports are higher than under FDI, even without taking relocation costs into account. Thus for FDI to be profitable, $\hat{F}$ has to be positive.

From Lemma 4.2, this implies:[9]

Proposition 1: *The foreign firm prefers FDI to exports for low enough relocation costs F if and only if:*

$$\frac{a_f^R\left(3+4\lambda_h\right)-a_h\left(1+4\lambda_h\right)}{6+8\lambda_h} > \frac{2\lambda_h a_f^x + a_f^x - a_h}{1+2\lambda_f+3\lambda_h+4\lambda_f\lambda_h}, \tag{31}$$

and this along with $q_h^R > 0$ is satisfied only if

$$\lambda_h < \lambda_f.$$

To explain the intuition behind this result, we substitute the profits under export and under FDI from (9) and (23) to rewrite condition (31) as:

$$\frac{2\left(a_f^x - t_f^x\right)-\left(a_h - t_h^x\right)}{3} < \frac{2a_f^R - a_h - t_h^R}{3}.$$

[9] The proof for $\lambda_h < \lambda_f$ is in Appendix B.

Rearranging yields:

Corollary 1: *The foreign firms prefers FDI to export for low enough relocation cost F if and only if*

$$\left(t_h^R + c_h\right) - \left(t_h^x + c_h\right) > 2\left[\left(t_h^R + c_f^R\right) - \left(t_f^x + c_f^x\right)\right],$$

i.e. the home firm's increase in full marginal cost is more than twice the foreign firm's increase.

We see that although FDI raises the foreign firm's own cost, it can still be worthwhile for the firm to relocate, as FDI may raise its competitor's cost by even more. As Lemma 4.1 has shown, the home government increases its environmental tax rate with FDI, because domestic production and pollution will be higher with two firms in the country than with one firm. It is therefore clear that FDI raises the home firm's costs. FDI also raises the foreign firm's costs by assumption (3) which we have made to rule out lower costs as a motive for FDI.[10]

3.3 Equal Production Costs

In this section we examine the special case where the marginal costs of production of the foreign firm under export and under FDI are equal to the marginal cost of production of the domestic firm:

$$a_f^R = a_f^x = a_h = a. \tag{32}$$

This enables us to have a closer look at the conditions under which the foreign firm will undertake FDI and to compare the countries' welfare under FDI and exports.

Lemma 4.2 now becomes:

Lemma 3: *Under condition (32), the foreign firm prefers FDI to exporting if and only if its fixed cost of relocation F is below $\tilde{F}$; where*

$$\tilde{F} \equiv \left[\frac{2a}{8\lambda_h + 6}\right]^2 - \left[\frac{2a\lambda_h}{1 + 2\lambda_f + 3\lambda_h + 4\lambda_f\lambda_h}\right]^2.$$

[10] Corollary 1 is in line with Oster (1982) and Michaelis (1994). However, they do not model the way in which regulation leads to a differential cost increase for the two firms.

Proposition 4.1 now becomes:

Proposition 2: *Under condition (32), the foreign firm prefers FDI to exporting for low enough relocation cost F if and only if:*

$$\lambda_f > \frac{8\lambda_h^2 + 3\lambda_h - 1}{2(2\lambda_h + 1)}. \tag{33}$$

In Figure 1, this condition is satisfied above the "FDI" curve.

Corollary 1 now becomes:

Corollary 2: *Under condition (32), the foreign firm prefers FDI to exporting for low enough relocation cost F if and only if:*

$$t_h^R - t_h^x > 2\left(t_h^R - t_f^x\right),$$

i.e. the tax increase for the domestic firm is at least twice the increase for the foreign firm.

Condition (6) that ensures that costs for the foreign firm are larger in the home country now becomes $t_h^R > t_f^x$. From (26) and (32) this holds when:

$$\lambda_f < \frac{7 + 16\lambda_h}{4}. \tag{34}$$

In Figure 1, this condition is satisfied below the line marked "$t_h^R > t_f^x$".

From (16) and the analysis in (29) and (28), we see that the output levels $q_f^R, q_h^R, q_h^x, q_f^x$ will always be positive with (32). The condition for $t_f^x > 0$ is $\lambda_f > \frac{1}{4}$,as in (19). The condition is not shown in Figure 1, because it can be seen from the figure that it will never be binding. Substituting (32) into (18), we see that $t_h^x > 0$ holds when:

$$\lambda_h > \frac{1 + 2\lambda_f}{1 + 4\lambda_f}. \tag{35}$$

In Figure 1, this condition is satisfied to the right of the curve marked "$t_h^x > 0$".

The two shaded areas in Figure 1 indicate the parameter range where the foreign firm prefers to undertake FDI although it will have to pay a higher environmental tax.

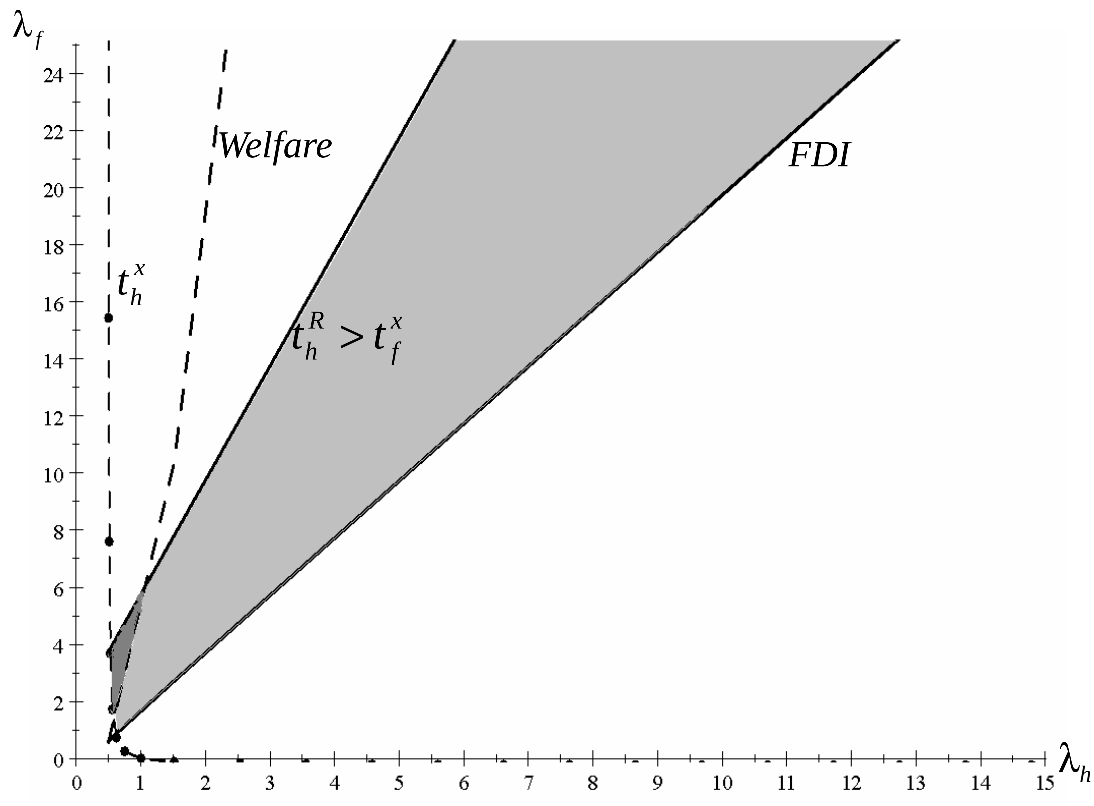

Figure 1: Environmental damage coefficients λ_f and λ_h where FDI is preferred over exports under Cournot Competition

3.4 Welfare

In this section we will compare the two countries' welfare with FDI and export under the condition (32), i.e. all marginal production costs are equal.

Substituting (32), the profit of the domestic firm under export (20), the environmental tax rate (14), and the quantity produced by the domestic firm (16) into the welfare function of the home country (12), we find

$$W_h^x = \frac{a^2\left(8\lambda_h\lambda_f^2 + 4\lambda_h^2 + 12\lambda_f\lambda_h + 4\lambda_h + 4\lambda_f^2 + 4\lambda_f + 1\right)}{\left(1 + 2\lambda_f + 3\lambda_h + 4\lambda_f\lambda_h\right)^2}. \quad (36)$$

Substituting (32), the profit of the domestic firm under FDI (30), the environmental tax rate (25) and the quantity produced by the domestic and the foreign firm under FDI (27) into the welfare function of the home country (24), we find:

$$W_h^R = \frac{a^2}{3+4\lambda_h}. \tag{37}$$

From (36), we see that:

$$\frac{\delta W_h^x}{\delta \lambda_f} = -\frac{4a^2\lambda_h^2\left(3+8\lambda_h\right)}{\left(1+2\lambda_f+3\lambda_h+4\lambda_f\lambda_h\right)^3} < 0. \tag{38}$$

It then follows from (36) to (38) that the home country's welfare is higher with exports:[11]

$$W_h^x > \frac{a^2}{1+2\lambda_h} > \frac{a^2}{3+4\lambda_h} = W_h^R.$$

The first inequality follows from (38) and letting $\lambda_f \to \infty$ in (36).

Substituting (32), the profit of the foreign firm under export (20), the environmental tax rate (15), and the quantity produced by the domestic firm (16) into the welfare function of the home country (10), we find:

$$W_f^x = 2\left(1+2\lambda_f\right)\left(\frac{\lambda_h a}{1+2\lambda_f+3\lambda_h+4\lambda_f\lambda_h}\right)^2. \tag{39}$$

Under FDI, the foreign country's welfare is equal to its firm's profits. By (30) and (32):

$$W_f^R = \left[\frac{2a}{8\lambda_h+6}\right]^2 - F.$$

Now define:

$$\tilde{W}_f^R = W_f^R + F = \left[\frac{2a}{8\lambda_h+6}\right]^2 \tag{40}$$

From (39) and (40) we find that $W_f^x > (<)\, \tilde{W}_f^R$ for $\lambda_f > (<)\, \tilde{\lambda}_f$,where

$$\tilde{\lambda}_f \equiv \frac{16\lambda_h^4+24\lambda_h^3+3\lambda_h^2-5\lambda_h-1+\lambda_h\left(3+4\lambda_h\right)\sqrt{\lambda_h\left(16\lambda_h^3+24\lambda_h^2-5\lambda_h-2\right)}}{2\left(1+2\lambda_h\right)^2}. \tag{41}$$

The $\tilde{\lambda}_f$ curve is drawn in Figure 1 as "Welfare". To the left of this curve, foreign welfare is higher with FDI if fixed cost F is low enough. To the right of the curve, foreign welfare is unambiguously higher with exports. As can be

[11] In a different context, similar welfare implications are found in De Santis and Stähler (2006).

seen in Figure 1, as well as from (40) and (41), foreign welfare is higher with exports for all values of λ_h above 1.2.

We conclude that the home country is definitely worse off and the foreign country is probably worse off when the foreign firm decides to undertake FDI rather than to export. The fall in domestic welfare is due to the reductions in consumer surplus, the profits of the domestic firm and environmental quality. The increase in environmental tax revenues is not enough to compensate for these losses. The foreign country's welfare falls under FDI as the increase in profit and in environmental quality is not enough to compensate for the loss of environmental tax revenue under export regime. Although the foreign firm's decision to undertake FDI may make both countries worse off, the countries' governments have no way of discouraging FDI because, by assumption, they cannot credibly commit to environmental policies before the firm's location decision.

For simplicity, we analyzed the welfare of both countries assuming equal marginal production costs. Qualitatively the results under the welfare analysis will be same even when the marginal production costs are different. When introducing cost asymmetry, following (1) with higher cost of the foreign firm under FDI, the profit of the foreign firm will fall further than with cost symmetry. Thus the welfare of the foreign country will be unambiguously lower with FDI when introducing cost asymmetry.

In the case of the home country, welfare under export is higher with equal marginal production cost. When introducing asymmetry, we see that with the foreign firm's cost higher under FDI than under export, domestic welfare under export will be lower than with cost symmetry. Thus welfare under export will be higher even with cost asymmetry.

4 Bertrand Case

Under the Bertrand case analysis, we assume that firm h and firm f produce differentiated products and compete as Bertrand duopolists in the home and foreign markets as in Clarke and Collie (2003). The marginal cost of production of the domestic firm is constant and equal to c_h while the marginal cost of production of the foreign firm is constant and equal to c_f^x under exports (where c_f^x also includes the transportation cost) and c_f^R under FDI.[12]

We assume that:

$$c_f^R \geq c_f^x. \tag{42}$$

Similar to the Cournot case, we assume that there is market demand only in the home country and there is a representative consumer with quasi-linear preferences that are described by a quadratic utility function. The utility function of the representative consumer is:

$$U = q_h + q_f - \frac{1}{2}\left(q_h^2 + q_f^2 + 2\phi q_h q_f\right) + z \tag{43}$$

where z is consumption of the numeraire good which is produced by a perfectly competitive industry using constant returns to scale technology. The parameters of the utility function are assumed to satisfy the following conditions: the maximum willingness to pay of consumers exceeds the marginal cost of the firms, $1 > c > 0$; and the products of the two firms are imperfect substitutes, $0 < \phi < 1$. It turns out that ■ is a key parameter in the model that measures the degree of product substitutability, where $\phi = 1$ means that the products of the two firms are perfect substitutes and $\phi = 0$ means that the two products are independent.

In addition to (42), we impose a condition on the parameters such that:

$$t_h^R + c_f^R > t_f^x + c_f^x, \tag{44}$$

i.e. full marginal costs (including production and transport costs as well as environmental taxation) are higher with FDI than with exports. We impose this condition to make sure that the foreign firm does not relocate in order to take

[12] Subscripts $i, i = f, h$, refer to the foreign and home firm or country, respectively. Superscripts $s, s = x, R$ refer to the scenario where the foreign firm is exporting and relocating, respectively.

advantage of lower costs in the home country.Using (58) and (67) where and are solved for, we can write condition (44) in terms of exogenous parameters as:

$$\lambda_f < \frac{1}{2}\frac{\begin{array}{c}-4K - 8K\lambda_h - \phi^2 + \phi^3 + \phi^4 - \phi^5 + \phi^2 c_f^x - \phi^4 c_f^x + 4K\phi^2 \\ -2\phi^2\lambda_h + 2\phi^4\lambda_h - \phi^3 c_h + \phi^5 c_h + 2\phi^2\lambda_h c_f^x - 2\phi^4\lambda_h c_f^x + 6K\phi^2\lambda_h\end{array}}{\left(2-\phi^2\right)\left(K - \phi + 2\lambda_h + 2K\lambda_h - c_f^x + \phi c_h - 2\lambda_h c_f^x + 1\right)} \tag{45}$$

where

$$K = \left(-c_f^R + c_f^x + \frac{\left(\begin{array}{c}-16\lambda_h - 2c_h + 2c_f^R - 8\phi\lambda_h - \phi^3 c_f^R - 3\phi c_h \\ +8\lambda_h c_h + \phi^3 c_h + 3\phi c_f^R + 8\lambda_h c_f^R + 4\phi\lambda_h c_f^R + 4\phi\lambda_h c_h\end{array}\right)}{2\left(\phi+2\right)\left(\phi + 4\lambda_h - \phi^2 + 2\right)} \right)$$

Utility maximisation, subject to the budget constraint, yields the inverse demand functions facing the two firm:

$$p_i = 1 - (q_i + \phi q_{-i}) \tag{46}$$

Substituting (46) into (43), the utility of the representative consumer with income I is:

$$U = \frac{1}{2}q_f^2 + \phi q_f q_h + \frac{1}{2}q_h^2 + I$$

In a Bertrand duopoly, where price is the strategic variable of the firms, the direct demand functions will generally be more useful than the inverse demand functions; inverting (46) yields the direct demand functions in the home market as:

$$q_i^s = \frac{1}{\left(1-\phi^2\right)}\left((1-\phi) - p_i^s + \phi p_{-i}^s\right) \tag{47}$$

4.1 Government Policy

4.1.1 Under Export

In this sub-game the foreign firm has decided, in stage one, to export. We start our analysis in stage three, where the two firms i, $i = f, h$, set the output levels that maximize their profits Π_i^x.

The profit of the two firms from sales in the home market are:

$$\pi_i^s = (p_i^s - c_i - t_i^s)\, q_i^s \tag{48}$$

The first-order conditions for the Bertrand equilibrium are:

$$\frac{d\left(\pi_i^s q_i^s\right)}{dp_i^s} = \frac{1}{\left(1-\phi^2\right)}\left(c_i - \phi - 2p_i^s + t_i^s + \phi p_{-i}^s + 1\right) \tag{49}$$

with π_h^s , π_f^s given by (48) and q_h^s , q_f^s given by (47).

The first-order conditions for the Bertrand equilibrium from (49)can be rearranged to give the best-reply functions of the home and the foreign firm as:

$$p_i^x = \frac{1}{2}\left(1 - \phi + c_i^x + t_i^x + \phi p_{-i}^x\right)$$

The intersection of the two bestreply functions, gives the prices of the two firms in the symmetric Bertrand equilibrium:

$$p_i^x = \frac{2 - \phi + 2c_i^x + 2t_i^x - \phi^2 + \phi c_{-i} + \phi t_{-i}^x}{(2-\phi)(\phi+2)} \tag{50}$$

Substituting these prices (50) into the direct demand functions (47) yields the sales of the two firms in the Bertrand equilibrium:

$$q_i^x = \frac{\left(\phi c_{-i}^x - \phi^2 - \phi + \phi t_{-i}^x + 2\right) - \left(2-\phi^2\right)\left(c_i + t_i^x\right)}{\left(1-\phi^2\right)\left(4-\phi^2\right)} \tag{51}$$

Using the prices from (50) and quantities (51) in (48) yields the profits of the two firms in the Bertrand equilibrium:

$$\pi_i^x = \frac{\left(\left(\phi c_{-i}^x - \phi^2 - \phi + \phi t_{-i}^x + 2\right) - \left(2-\phi^2\right)\left(c_i + t_i^x\right)\right)^2}{\left(1-\phi^2\right)\left(4-\phi^2\right)^2}. \tag{52}$$

In stage two, the home and foreign governments set the environmental tax rates that maximize social welfare. Social welfare Wi in country i $(i = h, f)$ is the sum of firm i's profit, consumer surplus (for the home country) and environmental tax revenue, minus environmental damage.

The foreign government maximizes:

$$W_f^x = \Pi_f^x + t_f^x q_f^x - \lambda_f \left(q_f^x\right)^2, \tag{53}$$

with Π_f^x given by (52) and q_f^x given by (51). Differentiating and solving for t_f^x, we get:

$$t_f^x = \frac{1}{2}\frac{\left(-\phi - \phi^2 - 2c_f^x + \phi^2 c_f^x + \phi c_h + \phi t_h^x + 2\right)\left[2\lambda_f\left(2-\phi^2\right) + \phi^2\left(1-\phi^2\right)\right]}{\left(2-\phi^2\right)\left(2\lambda_f - 2\phi^2 - \phi^2\lambda_f + 2\right)}. \tag{54}$$

Similarly the home government maximizes:

$$W_h^x = \Pi_h^x + \left(\frac{1}{2}\left(q_h^x\right)^2 + \phi\left(q_h^x\right)\left(q_f^x\right) + \frac{1}{2}\left(q_f^x\right)^2\right) + t_h^x q_h^x - \lambda_h\left(q_h^x\right)^2, \tag{55}$$

with Π_h^x given by (52) and q_h^x given by (51). Differentiating and solving for t_h^x, we get:

$$t_h^x = \frac{\begin{array}{c} 8\lambda_h + 4c_h + 9\phi^2 - 6\phi^4 + \phi^6 - 4\phi\lambda_h - 8\lambda_h c_h - 8\phi^2\lambda_h + 2\phi^3\lambda_h + 2\phi^4\lambda_h - 9\phi^2 c_h \\ +6\phi^4 c_h - \phi^6 c_h + 8\phi^2\lambda_h c_h - 2\phi^4\lambda_h c_h + 4\phi\lambda_h c_f^x + 4\phi\lambda_h t_f^x - 2\phi^3\lambda_h c_f^x - 2\phi^3\lambda_h t_f^x - 4 \end{array}}{8\lambda_h - 5\phi^2 + \phi^4 - 8\phi^2\lambda_h + 2\phi^4\lambda_h + 4}. \tag{56}$$

Substituting (54) into (56) and solving for t_h^x we get:

$$t_h^x = \frac{\left(\begin{array}{c} \left(4c_h + 2\phi^2 - 2\phi^2 c_h - 4\right)\lambda_f\lambda_h + \left(\phi^4 - 3\phi^2 - 2c_h + 3\phi^2 c_h - \phi^4 c_h + 2\right)\lambda_f + \\ \left(2\phi + 4c_h + 3\phi^2 - \phi^3 + \phi^3 c_f^x - 3\phi^2 c_h - 2\phi c_f^x - 4\right)\lambda_h \\ + \left(2\phi^4 - 4\phi^2 - 2c_h + 4\phi^2 c_h - 2\phi^4 c_h + 2\right) \end{array}\right)}{-2\lambda_f - 4\lambda_h + 2\phi^2 - 4\lambda_f\lambda_h + \phi^2\lambda_f + 3\phi^2\lambda_h + 2\phi^2\lambda_f\lambda_h - 2}. \tag{57}$$

From (57), we see that $t_h^x > 0$ when:

$$\lambda_h > \frac{\left(1-\phi^2\right)\left(2\lambda_f - 2\phi^2 - \phi^2\lambda_f + 2\right)\left(1-c_h\right)}{4 - 2\phi + 4\lambda_f - 4c_h - 3\phi^2 + \phi^3 - \phi^3 c_f^x - 4\lambda_f c_h - 2\phi^2\lambda_f + 3\phi^2 c_h + 2\phi c_f^x + 2\phi^2\lambda_f c_h}$$

Substituting (57) into (54) and solving for t_f^x we get:

$$t_f^x = \frac{1}{2}\frac{\left(4\lambda_f + \phi^2 - \phi^4 - 2\phi^2\lambda_f\right)\left(-\phi + 2\lambda_h - c_f^x + \phi c_h - 2\lambda_h c_f^x + 1\right)}{2\lambda_f + 4\lambda_h - 2\phi^2 + 4\lambda_f\lambda_h - \phi^2\lambda_f - 3\phi^2\lambda_h - 2\phi^2\lambda_f\lambda_h + 2}. \tag{58}$$

From (58), we see that $t_f^x > 0$ when:

$$\lambda_f > \frac{1}{2}\phi^2\left(1-\phi\right)\frac{\phi+1}{2-\phi^2}$$

Substituting (57) and (58) into (51), we find the equilibrium output levels as:

$$q_h^x = \frac{1}{2}\frac{-\phi+4\lambda_f-4c_h-3\phi^2+\phi c_f^x-4\lambda_f c_h-2\phi^2\lambda_f+3\phi^2 c_h+2\phi^2\lambda_f c_h+4}{2\lambda_f+4\lambda_h-2\phi^2+4\lambda_f\lambda_h-\phi^2\lambda_f-3\phi^2\lambda_h-2\phi^2\lambda_f\lambda_h+2} \tag{59a}$$

$$q_f^x = \frac{1}{2}\left(2-\phi^2\right)\frac{-\phi+2\lambda_h-c_f^x+\phi c_h-2\lambda_h c_f^x+1}{2\lambda_f+4\lambda_h-2\phi^2+4\lambda_f\lambda_h-\phi^2\lambda_f-3\phi^2\lambda_h-2\phi^2\lambda_f\lambda_h+2} \tag{59b}$$

The conditions for the q_f^x and q_h^x to be positive are respectively are:

$$\lambda_h > \frac{1}{2}\frac{\phi+c_f^x-\phi c_h-1}{1-c_f^x}$$

$$\lambda_f > \frac{1}{2}\frac{\phi+4c_h+3\phi^2-3\phi^2 c_h-\phi c_f^x-4}{\left(2-\phi^2\right)(1-c_h)}$$

Substituting (59a),(59b), (57) and (58) into the profit function (52), we get the profits of both firms when the foreign firm is exporting:

$$\Pi_h^x = \frac{1}{4}\frac{\left(1-\phi^2\right)\left(-\phi+4\lambda_f-4c_h-3\phi^2+\phi c_f^x-4\lambda_f c_h-2\phi^2\lambda_f+3\phi^2 c_h+2\phi^2\lambda_f c_h+4\right)^2}{\left(2\lambda_f+4\lambda_h-2\phi^2+4\lambda_f\lambda_h-\phi^2\lambda_f-3\phi^2\lambda_h-2\phi^2\lambda_f\lambda_h+2\right)^2} \tag{60}$$

$$\Pi_f^x = \frac{1}{4}\frac{\left(1-\phi^2\right)\left(2-\phi^2\right)^2\left(-\phi+2\lambda_h-c_f^x+\phi c_h-2\lambda_h c_f^x+1\right)^2}{\left(2\lambda_f+4\lambda_h-2\phi^2+4\lambda_f\lambda_h-\phi^2\lambda_f-3\phi^2\lambda_h-2\phi^2\lambda_f\lambda_h+2\right)^2}. \tag{61}$$

4.1.2 Foreign firm has undertaken FDI

In this sub-game the foreign firm has decided, in stage one, to relocate its plant to the home country. In stage three, each firm sets the output level that maximizes its profits. The profit of the two firms from sales in the home market are:

$$\max_{q_i^R} \Pi_i^R = \left(p_i^R - c_i^R - t_h^R\right) q_i^R - F_i \tag{62}$$

with $c_h^R = c_h$ and fixed cost $F_f = F, F_h = 0$.The first-order conditions for the Bertrand equilibrium are:

$$\frac{d\left(\pi_i^R q_i^R\right)}{dp_i^R} = \frac{1}{\left(1-\phi^2\right)}\left(c_i-\phi-2p_i^R+t_h^R+\phi p_{-i}^R+1\right)$$

with π_h^R , π_f^R given by (62) and q_h^R , q_f^R given by (47).

These first-order conditions can be rearranged to give the best-reply functions of the home and the foreign firm as:

$$p_i^R = \frac{1}{2}\left(1 - \phi + c_i^R + t_h^R + \phi p_{-i}^R\right)$$

The intersection of the two best reply functions, gives the prices of the two firms in the symmetric Bertrand equilibrium:

$$p_i^R = \frac{2 - \phi + 2c_i^R + 2t_h^R - \phi^2 + \phi c_{-i} + \phi t_h^R}{(2-\phi)(\phi+2)} \tag{63}$$

Substituting the prices from (63) into the direct demand functions (47) yields the sales of the two firms in the Bertrand equilibrium:

$$q_i^R = \frac{2 - \phi - 2c_i - 2t_h^R - \phi^2 + \phi c_{-i}^R + \phi t_h^R + \phi^2 c_i + \phi^2 t_h^R}{(1-\phi)(\phi+1)(2-\phi)(\phi+2)} \tag{64}$$

Using the prices from (63) and quantities (64) in (62) yields the profits of the two firms in the Bertrand equilibrium:

$$\pi_i^R = \frac{\left(2 - \phi - 2c_i^R - 2t_h^R - \phi^2 + \phi c_{-i} + \phi t_h^R + \phi^2 c_i^R + \phi^2 t_h^R\right)^2}{(1-\phi)(\phi+1)(\phi-2)^2(\phi+2)^2} \tag{65}$$

In stage two of the game, the home government sets the welfare maximising environmental tax rate:

$$\max_{t_h^R} W_h = \Pi_h^R + \left(\frac{1}{2}\left(q_h^R\right)^2 + \phi\left(q_h^R\right)\left(q_f^R\right) + \frac{1}{2}\left(q_f^R\right)^2\right) + t_h^R\left(q_h^R + q_f^R\right) - \lambda_h\left(q_h^R + q_f^R\right)^2. \tag{66}$$

with Π_h^R given by (65) and q_h^R and q_f^R by (64). Taking the first order condition and simplifying for t_h^R, we get:

$$t_h^R = \frac{1}{2}\frac{\begin{array}{c}16\lambda_h - 2c_f^R + 2c_h + 8\phi\lambda_h - 3\phi c_f^R + 3\phi c_h \\ -8\lambda_h c_f^R - 8\lambda_h c_h + \phi^3 c_f^R - \phi^3 c_h - 4\phi\lambda_h c_f^R - 4\phi\lambda_h c_h\end{array}}{(\phi+2)\left(\phi + 4\lambda_h - \phi^2 + 2\right)}. \tag{67}$$

We see that $t_h^R > 0$ when:

$$\lambda_h > \frac{1}{4}(2-\phi)(\phi+1)^2 \frac{c_f^R - c_h}{(\phi+2)\left(2 - c_h - c_f^R\right)}$$

Substituting the environmental tax rate (67) into the output levels of the firms (64) yields the profit maximizing output levels as follows:

$$q_f^R = \frac{1}{2}\frac{-2\phi - 3c_f^R - c_h - 2\phi^2 + 2\phi c_h - 4\lambda_h c_f^R + 4\lambda_h c_h + \phi^2 c_f^R + \phi^2 c_h + 4}{(1-\phi)(\phi+2)\left(\phi + 4\lambda_h - \phi^2 + 2\right)} \tag{68a}$$

$$q_h^R = \frac{1}{2}\frac{-2\phi + c_f^R - 5c_h - 2\phi^2 + 2\phi c_f^R + 4\lambda_h c_f^R - 4\lambda_h c_h - \phi^2 c_f^R + 3\phi^2 c_h + 4}{(1-\phi)(\phi+2)\left(\phi + 4\lambda_h - \phi^2 + 2\right)} \tag{68b}$$

The conditions for $q_f^R > 0$ and $q_h^R > 0$ are respectively:

$$\lambda_h < \frac{1}{4}\frac{-2\phi - c_h - 2\phi^2 - 3c_f^R + \phi^2 c_f^R + 2\phi c_h + \phi^2 c_h + 4}{c_f^R - c_h}$$

$$\lambda_h < \frac{1}{4}\frac{2\phi + 5c_h + 2\phi^2 - c_f^R + \phi^2 c_f^R - 3\phi^2 c_h - 2\phi c_f^R - 4}{c_f^R - c_h}$$

Finally, the two firms' profits are, substituting (67) into (62):

$$\Pi_f^R = \frac{1}{4}(\phi+1)\frac{\left(-2\phi - 3c_f^R - c_h - 2\phi^2 + 2\phi c_h - 4\lambda_h c_f^R + 4\lambda_h c_h + \phi^2 c_f^R + \phi^2 c_h + 4\right)^2}{(1-\phi)(\phi+2)^2\left(\phi + 4\lambda_h - \phi^2 + 2\right)^2} - F \tag{69}$$

$$\Pi_h^R = \frac{1}{4}(\phi+1)\frac{\left(2\phi - c_f^R + 5c_h + 2\phi^2 - 2\phi c_f^R - 4\lambda_h c_f^R + 4\lambda_h c_h + \phi^2 c_f^R - 3\phi^2 c_h - 4\right)^2}{(1-\phi)(\phi+2)^2\left(\phi + 4\lambda_h - \phi^2 + 2\right)^2}. \tag{70}$$

4.2 Export or FDI?

Having analyzed the second (government policy) and third (firms' output) stages of the game in the previous section, we now move to stage one where the foreign firm decides between exporting and undertaking FDI. The foreign firm prefers FDI to exports if $\Pi_f^R > \Pi_f^x$.

Comparing the foreign firm's profits (69) under FDI and (61) under export, we find:

Lemma 4: *The foreign firm prefers FDI to exporting if and only if its fixed cost of relocation F is below $\hat{F}$, where*

$$\hat{F} \equiv \frac{1}{4}\frac{(\phi+1)\left(-2\phi - 3c_f^R - c_h - 2\phi^2 + 2\phi c_h - 4\lambda_h c_f^R + 4\lambda_h c_h + \phi^2 c_f^R + \phi^2 c_h + 4\right)^2}{(1-\phi)(\phi+2)^2\left(\phi + 4\lambda_h - \phi^2 + 2\right)^2}$$
$$-\frac{1}{4}\frac{\left(1-\phi^2\right)\left(2-\phi^2\right)^2\left(-\phi + 2\lambda_h - c_f^x + \phi c_h - 2\lambda_h c_f^x + 1\right)^2}{\left(2\lambda_f + 4\lambda_h - 2\phi^2 + 4\lambda_f\lambda_h - \phi^2\lambda_f - 3\phi^2\lambda_h - 2\phi^2\lambda_f\lambda_h + 2\right)^2}.$$

$\hat{F}$ may be negative, which means that profits under exports are higher than under FDI, even without taking relocation costs into account. Thus for FDI to be profitable, $\hat{F}$ has to be positive.

From Lemma 4.1, this implies

Proposition 3: *The foreign firm prefers FDI to exports for low enough relocation costs F if and only if:*

$$\frac{(\phi+1)\left(-2\phi-3c_f^R-c_h-2\phi^2+2\phi c_h-4\lambda_h c_f^R+4\lambda_h c_h+\phi^2 c_f^R+\phi^2 c_h+4\right)^2}{(1-\phi)(\phi+2)^2\left(\phi+4\lambda_h-\phi^2+2\right)^2} \tag{71}$$

$$> \quad \frac{\left(1-\phi^2\right)\left(2-\phi^2\right)^2\left(-\phi+2\lambda_h-c_f^x+\phi c_h-2\lambda_h c_f^x+1\right)^2}{\left(2\lambda_f+4\lambda_h-2\phi^2+4\lambda_f\lambda_h-\phi^2\lambda_f-3\phi^2\lambda_h-2\phi^2\lambda_f\lambda_h+2\right)^2},$$

and this along with $q_h^R > 0$ is satisfied only if

$$\lambda_h < \lambda_f.$$

To explain the intuition behind this result, we substitute the profits under export and under FDI from (61) and (65) to rewrite condition (71) as:

$$\frac{\left(2-\phi-2c_f^R-2t_h^R-\phi^2+\phi c_h+\phi t_h^R+\phi^2 c_f^R+\phi^2 t_h^R\right)^2}{\left(1-\phi^2\right)\left(4-\phi^2\right)^2} > \frac{\left(\left(\phi c_h-\phi^2-\phi+\phi t_h^x+2\right)-\left(2-\phi^2\right)\left(c_f^x+t_f^x\right)\right)^2}{\left(1-\phi^2\right)\left(4-\phi^2\right)^2}.$$

Rearranging yields:

Corollary 3: *The foreign firms prefers FDI to export for low enough relocation cost F if and only if*:

$$\left[\left(t_h^R+c_h\right)-\left(t_h^x+c_h\right)\right] > \frac{\left(2-\phi^2\right)}{\phi}\left[\left(t_h^R+c_f^R\right)-\left(t_f^x+c_f^x\right)\right],$$

i.e. the home firm's increase in full marginal cost should be sufficiently higher than than that of the foreign firm´s adjusted by the degree of product differentiation.

We see that although FDI raises the foreign firm's own cost, it can still be worthwhile for the firm to relocate, as FDI may raise its competitor's cost by even more. As Lemma 4.1 has shown, the home government increases its environmental tax rate with FDI, because domestic production and pollution will be higher with two firms in the country than with one firm. It is therefore clear that FDI raises the home firm's costs. FDI also raises the foreign firm's costs by assumption (44) which we have made to rule out lower costs as a motive for FDI.

We further see from Corollary 1 that, this result would depend on the degree of product differentiation. If the degree of product differentiation is very high, i.e., $\phi \to 0$, the increase in the marginal cost of the home firm should be very high, for the foreign firm to find it profitable to relocate to the home country. Therefore, for FDI to take place, the products should not be sufficiently differentiated and higher degree of product differentiation would reduces the possibility of relocation by the foreign firm.

4.3 Equal Production Costs

In this section we examine the special case where the marginal costs of production of the foreign firm under export and under FDI are equal to the marginal cost of production of the domestic firm:

$$c_f^R = c_f^x = c_h = c. \tag{72}$$

Under condition (72), comparing the foreign firm's profits under FDI and under export from (69) and (61), we find:

Lemma 5: *The foreign firm prefers FDI to exporting if and only if its fixed cost of relocation F is below $\hat{F}$, where*

$$\hat{F} \equiv \frac{\left(1-\phi^2\right)\left(1-c\right)^2}{\left(\phi+4\lambda_h-\phi^2+2\right)^2} - \frac{1}{4}\frac{\left(1-\phi^2\right)\left(2-\phi^2\right)^2\left(1-c\right)^2\left(1-\phi+2\lambda_h\right)^2}{\left(2\lambda_f+4\lambda_h-2\phi^2+4\lambda_f\lambda_h-\phi^2\lambda_f-3\phi^2\lambda_h-2\phi^2\lambda_f\lambda_h+2\right)^2}$$

$\hat{F}$ may be negative, which means that profits under exports are higher than under FDI, even without taking relocation costs into account. Thus for FDI to be profitable, $\hat{F}$ has to be positive.

Under condition (72), the foreign firm prefers FDI to exporting for low *enough relocation cost F if and only if:*

$$\lambda_f > \left(\frac{1}{2} \frac{\begin{array}{c} -2\phi + 8\lambda_h - 2\phi^2 + 3\phi^3 + 2\phi^4 - \phi^5 + 16\lambda_h^2 \\ -8\phi^2\lambda_h^2 - 4\phi\lambda_h - 6\phi^2\lambda_h + 2\phi^3\lambda_h + 2\phi^4\lambda_h \end{array}}{\left(2-\phi^2\right)\left(2\lambda_h + 1\right)} \right). \tag{73}$$

Corollary 4.1 now becomes:

Corollary 4: *Under condition (72), the foreign firm prefers FDI to exporting for low enough relocation cost F if and only if:*

$$\left(t_h^R - t_h^x\right) > \frac{\left(2-\phi^2\right)}{\phi}\left(t_h^R - t_f^x\right)$$

i.e. the tax increase for the domestic firm should be sufficiently higher than than that of the foreign firm's, adjusted by the degree of product differentiation.

Condition (3) that ensures that costs for the foreign firm are larger in the home country now becomes $t_h^R > t_f^x$. From setting condition under *(72) in (25) and (15), we* see that this holds when:

$$\lambda_f < \frac{1}{2} \frac{\begin{array}{c} 16\lambda_h - 2\phi^2 + \phi^3 + 4\phi^4 - 2\phi^5 - 2\phi^6 + \phi^7 + 32\lambda_h^2 - 32\phi^2\lambda_h^2 \\ +8\phi^4\lambda_h^2 - 24\phi^2\lambda_h + 2\phi^3\lambda_h + 10\phi^4\lambda_h - 2\phi^5\lambda_h - 2\phi^6\lambda_h \end{array}}{\left(1-\phi\right)\left(2-\phi^2\right)\left(\phi + 4\lambda_h - \phi^2 + 2\phi\lambda_h + 2\right)} \tag{74}$$

From (68a),(68b), (59b) and (59a), we see that the output levels $q_f^R, q_h^R, q_h^x, q_f^x$ will always be positive with (72). Similarly, from (58) and (67), we see that t_f^x and t_h^R is positive with (72). Substituting (72) into (57), we see that $t_h^x > 0$ holds when:

$$\lambda_h > \left(1-\phi^2\right)\frac{2\lambda_f - 2\phi^2 - \phi^2\lambda_f + 2}{-2\phi + 4\lambda_f - 3\phi^2 + \phi^3 - 2\phi^2\lambda_f + 4}. \tag{75}$$

4.3.1 Illustration of the Bertrand Case when $\phi = 0.5$

Substituting $\phi = 0.5$,we can rewrite (73) the condition for $\hat{F} > 0$ (the curve marked in red) as:

$$\lambda_f > \frac{0.285\,71}{2\lambda_h + 1}\left(14.0\lambda_h^2 + 4.875\lambda_h - 1.031\,3\right)$$

In Figure 2, this condition is satisfied above the "FDI" curve.

Substituting $\phi = 0.5$,and inverting we can rewrite (75) the condition for $t_h^x > 0$ (the curve marked in red) as:

$$\lambda_f > -\frac{38\lambda_h - 18}{56\lambda_h - 21}$$

In Figure 2, this condition is satisfied to the right of the curve marked "$t_h^x > 0$".

Substituting $\phi = 0.5$,we can rewrite (74) the condition for $t_f^x < t_h^R$ (the curve marked in black) as:

$$\lambda_f < \frac{1}{56}\frac{1380.0\lambda_h + 3136.0\lambda_h^2 - 27.0}{20.0\lambda_h + 9.0}$$

In Figure 2, this condition is satisfied below the line marked "$t_h^R > t_f^x$".

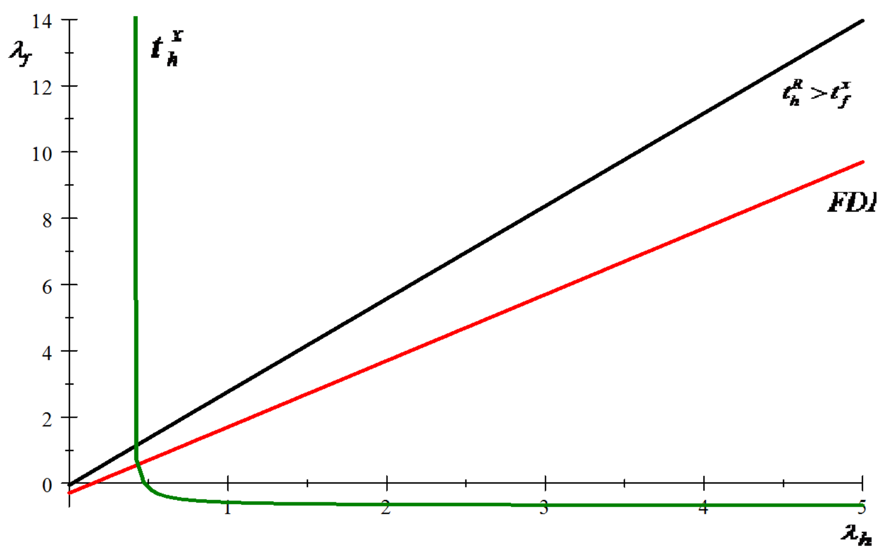

Figure 2: Environmental damage coefficients λ_f and λ_h where FDI is preferred over exports under Bertrand Competition

5 Conclusion and Discussion

It is widely feared that lenient environmental regulation attracts investment by polluting firms. In this paper under both Cournot and Bertrand model duopoly settings, we show that the opposite can hold: A foreign firm may invest in the home country although total costs (taking the costs of production, environmental taxation and transportation into account) are higher there.

We have seen that while under Cournot duopoly model for the the investment to pay off, the increase in the competitor (home) firm's costs should be more than twice the amount of the foreign firm's own costs, under Bertrand duopoly setting, the competitors (home) firm´s cost increase should be sufficiently higher than that of the foreign firm´s adjusted by the degree of product differentiation. Both these are cases of raising one's rival's costs. The home firm's costs rise because of the increase in the environmental tax rate which is necessitated by the foreign firm's relocation decision. Since we have assumed that FDI raises the foreign firm's cost of production, the rise in the environmental stringency is the only reason for FDI.

For simplicity we have assumed a linear demand curve and constant marginal production costs. Introducing more general functional forms would, however, not change our basic result that a firm will undertake FDI in countries with higher cost and stricter environmental regulation, as long as the difference between the rival's cost increase and its own cost increase is large enough.

We have assumed there is a single domestic firm. When there are multiple domestic firms, their costs need to rise by less than twice the foreign firm's costs in order to make FDI profitable (cf. Michaelis, 1994). On the other hand, FDI will cause a smaller increase in the environmental tax rate with multiple domestic firms. We further also assume that neither firm can reduce their emissions by doing any abatement activities. If the firms do R&D for pollution abatement, the same results would hold as long as the R&D decision is made after the government sets the optimal environmental tax rate. If we assume that the firms could do pollution abatement, say by reducing the emission per unit of output, then subsequently the cost of the firms would decrease as the emission tax the firms have to pay would fall. This would imply that the cost increase for the home firm when the foreign firm relocates would be less and would result in less incentive to do FDI for the foreign firm.

We assume that there is market demand only in the home country for simplicity. Introducing market demand in the foreign country would result in possibilities like bilateral FDI, two plants for either firms or export only by either firms depending on factors like market sizes in countries, the fixed cost of relocation and the marginal environmental damage functions. De Santis and Stähler (2006) analyses these possibilities for the case of symmetric countries and firms. In our model with asymmetric firms and countries, finding the equilibrium would be difficult. However, if we restrict the analysis and assume that only the foreign firm is capable of doing FDI, the result would still hold as the foreign firm's relocation would lead to production for both markets leading to higher environmental pollution, higher tax and subsequently higher cost increase for the domestic firm.

6 Appendix

Appendix A. Proof of Lemma 1.

From (14) and (25):

$$t_h^R - t_h^x = \frac{a_f^R (3 + 4\lambda_h) - 6a_h}{6 + 8\lambda_h} - \frac{a_h}{2} + \frac{2a_h (1 + 2\lambda_f) + 2\lambda_h a_f^x}{1 + 2\lambda_f + 3\lambda_h + 4\lambda_f \lambda_h}. \tag{76}$$

From (27), $q_f^R > 0$ if and only if:

$$a_f^R (3 + 4\lambda_h) > a_h (1 + 4\lambda_h). \tag{77}$$

Thus we see that the minimum value $a_f^R (3 + 4\lambda_h)$ can take is $a_h (1 + 4\lambda_h)$ and the minimum value of a_f^x is a_f^R applying (77) to the first fraction on the R.H.S of (76) and (5) to the third fraction we get:

$$t_h^R - t_h^x = \frac{-4a_h}{3 + 4\lambda_h} + \frac{2a_h (1 + 2\lambda_f) + 2\lambda_h a_f^x}{1 + 2\lambda_f + 3\lambda_h + 4\lambda_f \lambda_h}. \tag{78}$$

Rearranging (77), we get:

$$a_f^R > \frac{a_h (1 + 4\lambda_h)}{(3 + 4\lambda_h)}. \tag{79}$$

Applying the minimum value of a_f^R from (79) into 78) yields:

$$t_h^R - t_h^x = \frac{2a_h [(2\lambda_f + 1)(4\lambda_h + 3) + \lambda_h (4\lambda_h + 1) - 2(1 + 2\lambda_f + 3\lambda_h + 4\lambda_f \lambda_h)]}{(3 + 4\lambda_h)(1 + 2\lambda_f + 3\lambda_h + 4\lambda_f \lambda_h)} > 0.$$

The second inequality follows because the term between square brackets in the numerator can be rewritten as:

$$(2\lambda_f + 1)(4\lambda_h + 3) + \lambda_h (4\lambda_h + 1) - 2(1 + 2\lambda_f + 3\lambda_h + 4\lambda_f \lambda_h) = 2\lambda_f + 1 + \lambda_h (4\lambda_h - 1) > 0.$$

The inequality follows from (19).

Appendix B. Proof of $\lambda_h < \lambda_f$ in Proposition 1.

Rewriting (31), the foreign firm will find it profitable to do FDI for low enough F if

$$\frac{a_f^R}{a_h} > \frac{2a_f^x (4\lambda_h + 3)(2\lambda_h + 1) + a_h \left[12\lambda_h^2 - \lambda_h - 5 + 2\lambda_f (4\lambda_h + 1)(2\lambda_h + 1)\right]}{a_h (3 + 4\lambda_h)(1 + 3\lambda_h + 2\lambda_f (1 + 2\lambda_h))}. \tag{80}$$

From (27), $q_h^R > 0$ if and only if:

$$\frac{a_f^R}{a_h} < \frac{4\lambda_h + 5}{4\lambda_h + 3}. \tag{81}$$

We will show that when $\lambda_f \leq \lambda_h$, inequalities (80) and (81) cannot hold simultaneously.

On differentiating the R.H.S of (80) with respect to λ_f we get:

$$\frac{d\left(\frac{2a_f^x(4\lambda_h+3)(2\lambda_h+1)+a_h\left(12\lambda_h^2-\lambda_h-5+2\lambda_f(4\lambda_h+1)(2\lambda_h+1)\right)}{a_h(3+4\lambda_h)(1+3\lambda_h+2\lambda_f(1+2\lambda_h))}\right)}{d\lambda_f} = -\frac{4}{a_h}\frac{(2\lambda_h+1)\left(a_f^x - a_h + 2\lambda_h a_f^x\right)}{\left(2\lambda_f + 3\lambda_h + 4\lambda_f\lambda_h + 1\right)^2} < 0.$$

The inequality follows from (17). Thus the R.H.S of (80) is decreasing in λ_f. This is because the higher environmental damage, the higher will be the environmental tax rate in the foreign country and the more inclined the foreign firm will be toward FDI. Thus the lowest possible value of the R.H.S in (80) for $\lambda_f \leq \lambda_h$ is where $\lambda_f = \lambda_h = \lambda$. A necessary condition for (80) to hold is then:

$$\frac{a_f^R}{a_h} > \frac{a_h(4\lambda+5)\left(4\lambda^2+\lambda-1\right) + 2a_f^x(3+4\lambda)(2\lambda+1)}{a_h(3+4\lambda)(4\lambda+1)(\lambda+1)}. \tag{82}$$

The R.H.S of (82) is increasing in a_f^x. The lowest possible value that the R.H.S can take is when a_f^x is at its minimum value, which by (5) is a_f^R. Thus setting $a_f^R = a_f^x$, a necessary condition for (82) to hold is:

$$\frac{a_f^R}{a_h} > \frac{a_h(4\lambda+5)\left(4\lambda^2+\lambda-1\right) + 2a_f^R(3+4\lambda)(2\lambda+1)}{a_h(3+4\lambda)(4\lambda+1)(\lambda+1)}.$$

Rearranging and solving for a_f^R/a_h yields:

$$\frac{a_f^R}{a_h} > \frac{4\lambda+5}{3+4\lambda}.$$

This is clearly irreconcilable with condition (81) for $q_h^R > 0$. On the other hand, if $\lambda_h < \lambda_f$, it would be possible for the foreign firm to prefer FDI and still face the domestic firm.

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