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Climate Policy with
Endogenous Plant Location
and Market Size Asymmetry**

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Keywords: Foreign Direct Investment, Carbon Leakage, Climate Policy, Relocation, Transport Costs, Welfare

JEL Classification: F12, F23, Q58

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The impact of unilateral climate policy with endogenous plant location and market size asymmetry

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1. Introduction

The potential impact of unilateral climate policy on national firms' competitiveness and international location decisions is a key political issue both in the EU and the US. The main concern is that unilateral measures may lead national firms in carbon-intensive sectors to relocate production (and emissions) to countries not taking comparable actions, leading to considerable job losses and to a high degree of *carbon leakage*.¹

According to Reinaud (2008), there is carbon leakage if a policy aimed to limit emissions in a region is the direct cause of an increase in emissions outside the region itself.² This problem combines two related sensitive issues: the environmental effectiveness of mitigation policy (i.e. the emission leakage) and the impact on competitiveness and job losses (i.e. the job leakage). Official documents emphasize the first aspect, while in the political debate the attention shifts towards the second issue. Carbon leakage may take place via two competitiveness-driven channels: via changes in trade flows, and via foreign direct investment (FDI), that is through production relocation to countries not taking comparable mitigation actions.³ The FDI channel is a critical mechanism, as it leads to major discontinuous changes, with a high degree of irreversibility, in both emissions and production (and thus employment). That is why in the policy discussion most attention is given to what may be called as "relocation-driven carbon leakage", which implies considerable job losses.

The carbon leakage debate has been undergoing for sometime in the EU due to the unilateral adoption of the cap-and-trade scheme, denominated EU Emission Trading Scheme (EU ETS).⁴ These measures have created a more stringent environmental regime in the EU as compared to other geographical areas, and thus may have important repercussions on the competitiveness of European firms, particularly in energy-

¹Here we are dealing with pollution related to production. Measures aiming to reduce emissions related to consumption (such as in transport) do not affect firms' location choices.

² IPCC (2007) defines the carbon leakage rate as "the increase in CO₂ emissions outside the countries taking domestic mitigation action divided by the reduction in the emissions of these countries" (see IPCC, 2007, Technical Summary, p. 81).

³Reinaud (2008, p. 3) indicates that there is also a third channel (the fossil fuel price channel), but focuses on the two competitiveness-driven channel, as they can be more realistically addressed via national policies. Similarly, Neuhoff (2008) focuses on the two competitiveness-driven channel as they are at the centre of policy discussions.

⁴ The EU Emission Trading Scheme started with a pilot phase from 2005 to 2007, followed by a second trading period (2008-2012). The current debate concerns the new rules on the EU ETS third trading period (2013-2020). See http://ec.europa.eu/environment/climat/emission/implementation_en.htm and http://ec.europa.eu/environment/climat/emission/index_en.htm

intensive industries (Mc Kinsey, 2006; Bergmann et al., 2007; World Bank, 2008; OECD, 2009). A similar discussion is currently taking place in the US, where the American Clean Energy and Security Act (ACES) was approved in June 2009 by the House of Representatives,⁵ and is now under examination by the Senate.⁶ The fear of adverse impacts of environmental policies is heightened by the claims of energy-intensive industries across the Atlantic. EU producers have warned insistently that a tightened ETS will force them to move factories and jobs beyond the EU border, asking thus for compensatory measures.⁷ Similar claims were advanced by US producers.⁸ The question to assess is whether these fears are overrated or not.⁹

A related, although less policy-oriented, debate has been going on in the trade and environment literature concerning whether globalization will lead to the emergence of the so-called “*pollution havens*”. The pollution haven hypothesis (PHH) predicts that, due to the liberalisation of trade and FDI, firms active in pollution-intensive sectors and operating in countries adopting more restrictive environmental policies, will transfer production abroad and will serve the domestic markets from these new foreign plants (see e.g. Copeland and Taylor, 1994, 2003). As environmental policy becomes more restrictive with economic growth (being the environment a normal good), it is expected that in highly-polluting sectors production will move from developed to developing countries. However, while theoretical works converge in predicting such a shift, empirical research has not supported this prediction. In fact we may talk of a “pollution haven” paradox.¹⁰

The formal literature has generally overlooked the role of FDI, when addressing the carbon leakage and the pollution haven issues, notwithstanding that both phenomena

⁵ HR 2454, called also the Waxman-Markey bill.

⁶ Kerry-Lieberman Bill.

⁷ The Boston Consulting Group report commissioned by the European Cement Association (CEMBUREAU) (Boston Consulting Group, 2008) concludes that (p. 25) “The full auctioning of CO₂ allowances in 2020 would lead to offshoring of more than 80% of clinker production at a CO₂ price of € 25/t, while at CO₂ price of € 35/t, the entire EU clinker production will be at risk of carbon leakage”.

⁸ The American Chemistry Council in June 2009 stresses that “unilateral climate change policy has the potential to drive manufacturing production, jobs and greenhouse gas emission to overseas markets.....” thus supporting the proposal for rebates and border adjustments. See: http://www.americanchemistry.com/s_acc/bin.asp?CID=206&DID=9728&DOC=FILE.PDF

⁹ Analyses on the impact of EU ETS on the competitiveness of energy intensive and trade exposed industries have not found empirical evidence of a correlation between EU carbon prices and a loss of competitiveness. See Convery et al. (2008) and Reinaud (2008).

¹⁰ On the “pollution haven paradox” see: Ederington et al. (2005), Eskeland and Harrison (2003), Levinson and Taylor (2008), Smarzynska and Wei (2004), Spatareanu (2007) and Wagner and Timmins (2009).

are inherently linked with the effect of environmental measures on firms' choice of international location. Thus most studies on the PHH analyze the interaction of trade and environment (Fullerton, 2006) without taking into account the issue of firms' geographical mobility, although FDI represents an essential part of the PHH reasoning, as acknowledged by Taylor (2006)¹¹. Similarly, most CGE models analyze the likelihood of carbon leakage accounting only for effects via trade.

Furthermore, partial equilibrium models addressing FDI and environmental policy do not consider crucial aspects of the problem, losing much of their interest for empirical work or policy decisions. Early models (Markusen et al., 1993; Motta and Thisse, 1994), endogenizing the location decision but not environmental policy, accounted for most key location factors. These studies however were concerned with *symmetric countries* and considered local pollution.¹² During the last ten years, the main focus has shifted towards endogenizing environmental policy in a strategic context, while often taking the international strategy of firms as exogenous (e.g. Bayindir-Upmann, 2003; Kayalica and Lahiri, 2005; Cole et al., 2006). Only in a few papers both governments and firms decisions have been treated as endogenous (Markusen, et al., 1995; Rauscher, 1995; Hoel, 1997; Ulph and Valentini, 2001; Abe and Zhao, 2005; Ikefuji et al., 2010).

This strand of literature, in order to address both location and policy decisions, introduces drastic simplifications, assuming for instance that there are no transport costs, the two areas (adopting mitigation policy and not) have the same size, firms face the same plant fixed costs when producing at home or abroad,¹³ and pollution is local. Due to the combination of fixed plant costs with zero transport costs, in these analyses each firm operates only one plant; in the absence of fixed relocation costs this plant will always be located in the country with the lowest tax rates (Hoel, 1997). As a result of this very stylized setup, these models have three major shortcomings. They are unable to capture the different forms that relocation may assume and their specific welfare

¹¹ Taylor (2006), p. 5 underlines that there are two quite different concepts: the "pollution haven effect" (if more stringent environmental regulations lead only to changes in trade flows) and the "Pollution Haven Hypothesis" (which predicts that in pollution-intensive industries firms will relocate production).

¹² In addition Markusen et al. (1993) ruled out by assumption the total relocation outcome which is at the centre of the present debate. Motta and Thisse (1994) only briefly considered market size asymmetry, as discussed in section 3.

¹³ Ikefuji et al. (2010) allow for fixed relocation costs. However their model, with two domestic producers and no foreign competition, considers local pollution, zero transport costs (and thus one plant per firm) and sales in the foreign market are assumed away.

implications. In addition, by assuming symmetric markets, they tend to overrate the probability that total relocation will occur, offering theoretical support to companies' claims of a high risk of relocation-driven carbon leakage. Furthermore, they do not recognize that an essential aspect of the carbon leakage debate is the global (instead of local) nature of the negative environmental externality, and thus the effectiveness of environmental policy depends on global and not on domestic production.

In this paper we try to fill these gaps by presenting a simple two-stage international duopoly model on the impact of unilateral climate policy on firms' international location strategy and welfare, which allows for market size asymmetry between the two areas (with and without mitigation policies), transport costs, plant-specific fixed costs and considers global industrial pollution. As to plant fixed costs, we analyze both the case in which the existing capital stock has reached its economic end of life and that in which is still operating. The model thus captures the main centripetal and centrifugal forces driving the location decision when firms are confronted by unilateral climate measures (considered here as exogenous). Moreover it can tackle different types of relocation as firms may control more than one plant, showing that the welfare impact of unilateral climate measures are specific to the form undertaken by relocation.

The paper is organized as follows. Section 2 discusses the stylized facts on which to build a model. Section 3 presents the model, while Section 4 analyzes how the interaction between FDI and environmental policy is influenced by market size and plant costs asymmetries. Regions representing equilibrium outcomes are dealt with in Section 5 while Section 6 presents some welfare results. Section 7 briefly discusses carbon leakage provisions in EU and US climate policy and Section 8 draws the main conclusions.

2. Stylized facts and neglected location factors

As the effects of environmental measures on plant location are highly context-dependent, it is important to identify the main features of pollution-intensive sectors in order to define key stylised and empirically grounded facts on which to build a model.

The impact of industries on the environment may be measured by different indicators. Mani and Wheeler (1997) show that, if the level of abatement expenditure per unit of output is considered, five sectors emerge as "dirty industries": Iron and Steel,

Non-Ferrous Metals (such as aluminium), Industrial Chemicals, Pulp and Paper, and Non- Metallic Mineral Products (such as cement).

These sectors have some common features. Mani and Wheeler (1997) find that dirty industries are relatively intensive in capital, energy and land. The importance of capital intensity (and thus of fixed plant costs) in these sectors is underlined in several other studies (e.g. McKinsey & Company, 2006; Cole and Elliot, 2005; Bergmann et al., 2007). Furthermore, firms in these sectors produce bulk commodities with a high weight/value ratio and are thus characterized by large transportation costs (see Anderson and Wincoop, 2004; Hummels, 2007).

Let us consider as an illustration the case of cement production. This is a key industry, both from an economic and an environmental perspective. Cement is an essential input for the construction industry (highways, residential and commercial buildings, tunnels and dams) and cement plants account for 5% of global emissions of carbon dioxide (CO₂), the main cause of global warming. This industry is very energy-intensive¹⁴ and is included in the EU ETS. It is characterized by large capital start-up costs calculated by McKinsey (2006) to amount to 120 million Euro for a 1 million ton plant.¹⁵ Furthermore the average operating time of a plant is estimated to be 30 years.¹⁶ Cement production is also characterized by high transport costs as compared to unit value. Transport costs from Northern Africa or the Eastern European countries outside the EU to Antwerp have been estimated to reach 36% of unit variable production costs¹⁷; then markets are served largely via local production. In 2006 trade of cement and clinker (the primary input to cement) represented only 7% of world cement consumption.¹⁸

We argue therefore that fixed plant costs, transport costs and market size asymmetry are essential components of a model analyzing firms' responses to unilateral climate actions.

¹⁴ Energy costs may represent 30-40% of production costs (Cembureau, Competitiveness of European cement industry, www.cembureau.be).

¹⁵ In this capital intensive industry five large multinationals (Holcim, Lafarge, Cemex, HeidelbergCement, Italcementi) control around 58% in the EU25 market and 30% of the global cement market. See The Global Cement Report (7th edition), www.CemNet.com.

¹⁶ Boston Consulting Group (2008), p.12. OECD/IEA (2009), p. 54, reports that in general, significant modernisation investments need to be undertaken every 25-40 years for an aluminium smelter, 20-25 years for a blast furnace still mill, 25-30 years for a steel rolling mill, and 20 for cement kilns. However, the life span of these installations can reach up to 50 years.

¹⁷ McKinsey (2006), p. 37; Bergmann et al. (2007), p.24.

¹⁸ See The Global Cement Report (7th edition), www.CemNet.com. However the trade intensity varies considerably within sub-sectors.

3. The model

We present a two-country, two-firm international oligopoly model.¹⁹ Two groups of countries are considered: the first one consists of the cooperating nations that implement stricter mitigation measures (labelled country *I*) and a second group is formed by the non-cooperating countries (henceforth country *II*). The international oligopoly is formed by two firms (firm 1 and firm 2), which manufacture the same homogeneous good²⁰ in country *I* and *II* respectively. Firm 1's location strategy is endogenously determined by the model, while for simplicity firm 2's international strategy is given, as this firm may only export to the foreign market.²¹

Let us assume that country *I* sets a more stringent regulation on pollution emissions as compared to country *II*, introducing a pollution tax $t_I > t_{II}$, where t_{II} represents the common price of emissions in the two areas before the new measure is introduced.²² Such policy may have different repercussions on firm 1's location strategy.

Firm 1's location strategy space is given by $S_1 = \{NR, PR, TR\}$. The firm chooses “no relocation” (NR), when it continues to produce in the home country and to serve the foreign market via export;²³ in this case the tighter pollution tax has no impact on firm 1's location choice. If, on the contrary, there is a shift of production abroad, this may be either partial or total. There is “partial relocation” (PR) if the environmental measures stimulate the local firm to substitute export with foreign production, leading to a partial shift of production abroad. The firm will undertake a market-oriented FDI and have a plant in each country. There is “total relocation” (TR) if firm 1 moves all production abroad, and exports back to the home market. This is the case implicitly assumed in the pollution haven and carbon leakage debates.

Equilibrium is determined by solving a two-stage game. In the first stage firm 1 chooses its location strategy. In the second stage the two firms, competing *à la* Cournot,

¹⁹ For the monopoly case see Sanna-Randaccio and Sestini (2010), which does not present a welfare analysis.

²⁰ We did not consider intermediate products since, as indicated by Bergmann et al. (2007), p.1, energy intensive sectors generally form part of vertically integrated highly clustered value chains. Hanle et al. (2004), p. 7, indicates that 93% of plants in the US cement industry are integrated facilities. See www.epa.gov/ttnchie1/conference/ei13/ghg/hanle.pdf.

²¹ Firm 2, for instance, may face prohibitive fixed FDI costs due to the lack of international experience.

²² If many industries pollute and the firm considered is a price-taker in a competitive market for permits, the pollution tax is equivalent to the price of a permit per unit of output, and the analysis can be extended to an emission trading system. See Markusen et al. (1993) and Alexeeva –Talebi et al. (2008).

²³ We restrict the parameters range to values such that, after the introduction of t_I , it is still profitable for firm 1 to export, thus excluding the NE (no export) outcome in which firm 1 sells only in country *I*.

decide simultaneously how much to sell in each market (and therefore the level of output).

We allow for asymmetry in the size of the two countries, differently from most previous studies. A first attempt to address this issue was made by Motta and Thisse (1994), who analyze the effect of relative market size on location within very restrictive assumptions, considering only low transport costs, and disregarding this issue in the welfare analysis. Zeng and Zhao (2009) instead consider market asymmetry within a monopolistic competition model which does not allow for the export/FDI choice and, in case of FDI, for the choice between partial or total relocation.

3.1 Assumptions of the model

Before the introduction of the tighter pollution tax, firm 1 and firm 2 are based in country I and II respectively and export to the other country. Domestic and foreign inverse demand functions are assumed to be linear:

$$P_I = a_I - b_I(q_{1,I} + q_{2,I}) \quad (1)$$

$$P_{II} = a_{II} - b_{II}(q_{1,II} + q_{2,II}) \quad (2)$$

where $q_{i,K}$ denotes the output sold by firm i in country K (with $i = 1,2$, $K = I, II$) and the parameters a_K, b_K measure market size in country K . It follows that market size differences will be measured by a_I versus a_{II} and by b_I versus b_{II} .

The two firms face the same production technology, which is characterized by a constant marginal cost c and by a fixed cost $G_{i,K}$ (with $i = 1,2$, $K = I, II$) necessary to install a manufacturing plant. For the sake of simplicity we label each firm's home plant fixed cost as $G_{i,h}$, and the foreign plant fixed cost as $G_{i,f}$. There is also a fixed cost at the firm level (F), which captures firm-specific activities such as advertising, marketing, distribution and managerial services. Transport costs per unit of export are indicated by the parameter s , while the more stringent pollution tax in country I by $t_I > t_{II}$. We focus on global industrial pollution²⁴ and assume that emissions are proportional to output. The emission coefficient is set equal to 1, so that the level of emissions is given by the volume of production.²⁵

²⁴ This is the case of pollution emitted locally that has global effects (like GHGs).

²⁵ This is line with the CO₂ intensity of cement production reported by Bergmann et al. (2007), p. 26 and p. 83.

Firm 1 may choose to serve the foreign market via export or FDI, while firm 2 is by assumption an exporter. Export implies additional marginal (and unit) transport cost²⁶ s -with $s > t_{II}$ - whilst FDI involves additional plant specific fixed costs $G_{1,f}$ (associated to the new plant in the foreign market).²⁷ Thus export is the high marginal cost and low fixed cost option, and the reverse is the case for FDI. When total relocation takes place, firm 1 will have to bear transport costs to transfer the goods produced in country II to the home market.

Profits depend on the market configuration, which is influenced by firm 1's location choice. In the NR outcome there is one plant in each country; in the PR case there are one plant in country I and two in country II as firm 1 invest abroad; in the TR case firm 1's entire production is moved abroad, thus there is no plant in country I and two plants in country II . The objective functions in the different scenarios are reported in Appendix I.

3.2 Optimal profits

With “no relocation”, which implies that firm 1 produces only in country I and exports to the other country, we get that optimal profits are:

$$\hat{\pi}_1^{NR} = \frac{(a_I - c - 2t_I + s + t_{II})^2}{9b_I} + \frac{(a_{II} - c - 2t_I - 2s + t_{II})^2}{9b_{II}} - F - G_{1,h} \quad (3)$$

$$\hat{\pi}_2^{NR} = \frac{(a_I - c - 2s - 2t_{II} + t_I)^2}{9b_I} + \frac{(a_{II} - c - 2t_{II} + t_I + s)^2}{9b_{II}} - F - G_{2,h} \quad (4)$$

With “partial relocation”, that is if firm 1 chooses to serve the foreign market via local production opening a plant also in country II , we obtain that optimal profits are as follows:

$$\hat{\pi}_1^{PR} = \frac{(a_I - c - 2t_I + s + t_{II})^2}{9b_I} + \frac{(a_{II} - c - t_{II})^2}{9b_{II}} - F - G_{1,h} - G_{1,f} \quad (5)$$

$$\hat{\pi}_2^{PR} = \frac{(a_I - c - 2s - 2t_{II} + t_I)^2}{9b_I} + \frac{(a_{II} - c - t_{II})^2}{9b_{II}} - F - G_{2,h} \quad (6)$$

²⁶ The value of s may also capture other trade costs (see Anderson and Wincoop, 2004).

²⁷ This parameter also accounts for other additional fixed costs associated to FDI.

With “total relocation”, when firm 1 moves all production abroad and the home market is served by the foreign subsidiary, we obtain that optimal profits are given by:

$$\hat{\pi}_1^{TR} = \frac{(a_I - c - s - t_{II})^2}{9b_I} + \frac{(a_{II} - c - t_{II})^2}{9b_{II}} - F - G_{1,f} \quad (7)$$

$$\hat{\pi}_2^{TR} = \frac{(a_I - c - s - t_{II})^2}{9b_I} + \frac{(a_{II} - c - t_{II})^2}{9b_{II}} - F - G_{2,h} \quad (8)$$

4. The impact of unilateral climate policy on market structure

The impact of the introduction of a more stringent pollution tax in country I on the local firm’s location strategy will be assessed allowing for different degrees of asymmetry. Furthermore, we consider two cases, depending on the relative magnitude of transport costs (s) as compared to the differential between the pollution taxes ($t_I - t_{II}$). Thus we define as “*low transport costs*” the case with $s < (t_I - t_{II})$, that is when unit transport costs are lower than the additional environmental costs; on the contrary we call “*high transport costs*” the case with $s > (t_I - t_{II})$.

4.1 Full symmetry ($a_I = a_{II} = a$, $b_I = b_{II} = b$, $G_{1,f} = G_{1,h}$, $G_{i,h}$ not sunk)

Let us assume that the two countries have the same size ($a_I = a_{II}$, $b_I = b_{II}$). In addition, firm 1’s fixed plant costs are equal in both markets, which implies that the fixed costs associated to the home plant are not sunk, i.e. that the existing capital stock has reached its economic end of life. Furthermore, this scenario requires that for firm 1 there are no additional fixed costs to enter the foreign market, such as for instance costs due to language differences or costs of controlling production from a distance.

Comparing Eqs. (3), (5), (7) we can state:

Proposition I: *With full symmetry a more stringent environmental tax imposed by country I ($t_I > t_{II}$) will lead to some form of relocation (total or partial), except for extreme values of s .*

Proof: Setting $A = a - c$, we have that

$$\hat{\pi}_1^{TR} - \hat{\pi}_1^{NR} = \frac{4}{9b} \{ (t_I - t_{II}) [2(A - t_I) - s] - s^2 \} \quad (9)$$

With low transport costs Eq. (9) is always strictly positive since $(t_I - t_{II}) > s$, and $2(A - t_I) - s > s$ because of $\hat{q}_{1,II}^{NR} > 0$. Since, with $s \leq 3(t_I - t_{II})$, the term in curly

brackets in Eq. (9) is positive, in the high transport costs case a sufficient condition for $\hat{\pi}_1^{TR} - \hat{\pi}_1^{NR} > 0$ is that $s \leq 3(t_I - t_{II})$, that is if we exclude extreme values of s . \square

With symmetry in market size and plant costs, there is only one centripetal force (captured by the term s^2) discouraging firm 1 to choose TR, which may be labelled as the “lower competition” effect. By choosing TR firm 1 would in fact forego the benefits due to the cost asymmetry it enjoys *vis-à-vis* the foreign exporter when serving the home market via local production.²⁸ With low transport costs this centripetal force is always insufficient to compensate for the effect of the more stringent pollution tax which, by rising unit variable costs, stimulates the local firm to move production abroad. This is also generally the case with high transport costs. The “lower competition” effect is obviously not present if we consider an international monopoly (see Sanna-Randaccio and Sestini, 2010). In other words additional centripetal forces discouraging relocation are at work when there is foreign competition.

Furthermore, transport costs influence the characteristics of the process of relocation. We can state:

Proposition II : *With full symmetry and low transport costs (i.e. $s < (t_I - t_{II})$) relocation is total, that is all production is moved abroad when country I enacts unilaterally a more stringent climate policy. Instead, with high transport costs ($s > (t_I - t_{II})$) relocation may be total or partial.*

Proof:

It is straightforward to show that

$$\hat{\pi}_1^{TR} - \hat{\pi}_1^{PR} = \left\{ -\frac{4}{9b} [s - (t_I - t_{II})] (A - t_I) \right\} + G_{1,h} \quad (10)$$

Since $G_{1,h} > 0$, a sufficient condition for the expression in (10) to be strictly positive is that $s < (t_I - t_{II})$. On the other hand, with $s > (t_I - t_{II})$ the condition $\hat{\pi}_1^{TR} > \hat{\pi}_1^{PR}$ may hold for sufficiently low values of $G_{1,h}$. \square

With low transport costs, variable profits are higher with the TR than with the PR choice (the term in curly bracket is positive); this reinforces the effect of $G_{1,h}$, leading firm 1 to relocate all production abroad. Such result is in line with the

²⁸ A shift from NR to TR implies that firm 1 loses the protection from transport costs previously enjoyed in the home market, but at the same time it removes the competitive disadvantage previously faced as compared to the local producer in country II. The lower competition effect seems to suggest that the first effect prevail on the second.

conclusions of previous studies, assuming symmetric countries and zero transport costs (i.e. a special case of the low transport cost scenario), which found that unilateral climate actions lead to total relocation of domestic production. However, we show that with symmetric countries but high transport costs, the two forces in Eq. (10) (additional variable profits versus additional fixed costs) contrast each other and thus total relocation is not anymore inevitable, as partial relocation may instead take place.

4.2 Market size asymmetry and plant costs symmetry ($a_I > a_{II}$, $b_I < b_{II}$, $G_{1,f} = G_{1,h}$, $G_{i,h}$ not sunk)

Let us introduce now market size asymmetry, with country *I* being larger than country *II* (i.e. $a_I > a_{II}$, $b_I < b_{II}$). As before, firm 1 faces the same plant fixed costs in both countries. We obtain that, if the more stringent environmental tax ($t_I > t_{II}$) is imposed by the large country ($a_I > a_{II}$ and $b_I < b_{II}$), the level of transport costs plays a crucial role in determining whether or not market structure will change.

We could show that:

Proposition III *With high transport costs ($s > (t_I - t_{II})$), if the more stringent climate policy is imposed by the large country, the probability that neither partial nor total relocation takes place increases in market asymmetry.*

Proof:

Straightforward, as (given $A_i = a_i - c$)

$$\hat{\pi}_1^{NR} > \hat{\pi}_1^{TR} \quad \text{iff}$$

$$\frac{4}{9} \left\{ s \left[\frac{(A_I - t_I)}{b_I} - \frac{(a_{II} - c - t_I)}{b_{II}} \right] - (t_I - t_{II}) \left[\frac{(A_I - t_I)}{b_I} + \frac{(A_{II} - s - t_I)}{b_{II}} \right] + \frac{s^2}{b_{II}} \right\} > 0 \quad (11)$$

$$\text{and} \quad \frac{\partial(\hat{\pi}_1^{NR} - \hat{\pi}_1^{TR})}{\partial a_{II}} = -\frac{4}{9} \left[\frac{s + (t_I - t_{II})}{b_{II}} \right] < 0 \quad (12)$$

$$\text{with} \quad \frac{\partial(\hat{\pi}_1^{NR} - \hat{\pi}_1^{TR})}{\partial s} = \frac{4}{9} \left\{ \left[\frac{(A_I - t_I)}{b_I} - \frac{(A_{II} - t_I)}{b_{II}} \right] + \frac{t_I - t_{II}}{b_{II}} + \frac{2s}{b_{II}} \right\} > 0 \quad (13)$$

while:

$$\hat{\pi}_1^{NR} > \hat{\pi}_1^{PR} \quad \text{iff} \quad G_{1,f} > \frac{4}{9} \left[\frac{s + (t_I - t_{II})}{b_{II}} \right] (A_{II} - s - t_I) \quad (14)$$

$$\text{and } \frac{\partial(\hat{\pi}_1^{NR} - \hat{\pi}_1^{PR})}{\partial a_{II}} = -\frac{4}{9} \left[\frac{s + (t_I - t_{II})}{b_{II}} \right] < 0 \quad (15)$$

$$\text{with } \frac{\partial(\hat{\pi}_1^{NR} - \hat{\pi}_1^{PR})}{\partial s} = -\frac{4}{9} \left[\frac{A_{II} - 2s - 2t_I + t_{II}}{b_{II}} \right] < 0 \quad (16)$$

□

We may observe from Eq. (11) that no relocation will be chosen instead of total relocation if the two centripetal forces due to the “market asymmetry” effect (first term in curly brackets) and to “lower competition” effect (i.e. $\frac{s^2}{b_{II}}$) prevail on the centrifugal effect due to the environmental policy asymmetry (second term in curly brackets). If both Eqs. (11) and (14) are satisfied, a more stringent pollution tax in the large country (country *I*) will not modify the local firm’s location strategy.

When the size of the foreign market falls, being it measured by a decrease in a_{II} , and thus *ceteris paribus* the gap in market size becomes larger, the probability of choosing the no relocation strategy increases, as both condition (11) and (14) are decreasing in a_{II} (see (12) and (15)). As to the influence of transport costs, we find that an increase in s , while decreasing the probability of total relocation due to Eq. (13), increases the likelihood of partial relocation due to Eq. (16).

We may conclude that total relocation is a less likely outcome in sectors with high transport costs, when environmental policy is enacted by the large country ($a_I > a_{II}; b_I < b_{II}$). Even if $G_{1,h}$ is not sunk, market asymmetry associated to high transport costs may explain why a unilateral increase in the stringency of environmental policy by the large country may not result in local firms moving abroad. When considering symmetry in plant costs, that is if the economic life of the home plant has reached termination, plant economies of scale (specifically the size of the foreign plant $G_{1,f}$) play a key role only in firm 1 choice between not changing location strategy and serving each market by local production (NR *versus* PR). With $G_{1,h} = G_{1,f}$, plant economies of scale instead do not influence the choice between producing only at home and total relocation (NR *versus* TR).

On the other hand, with market asymmetry and low transport costs ($s < (t_I - t_H)$), a more stringent pollution tax set by country I results in all production shifting abroad (total relocation), as in the case of market size symmetry.²⁹

4.3 Plant costs asymmetry with market size symmetry ($G_{i,f} > G_{i,h}$, $a_I = a_H = a$; $b_I = b_H = b$).

We will focus on the case in which firms' existing capital stock has not yet reached its economic end of life, i.e. domestic plant costs are sunk ($G_{i,h} = 0$).³⁰ The two markets are assumed instead to be symmetric.

We find that:

Proposition IV *If fixed plant costs are higher when investing abroad, no relocation may be the optimal strategy both with low and high transport costs, even in the case of two symmetric markets.*

Proof:

It is straightforward to show that

$$\hat{\pi}_1^{NR} > \hat{\pi}_1^{TR} \text{ iff } G_{1,f} > \frac{4}{9b} \{(t_I - t_H)[2(A - t_I) - s] - s^2\}$$

and $\hat{\pi}_1^{NR} > \hat{\pi}_1^{PR}$ if Eq. (14) holds. □

Higher fixed plant costs for a firm investing abroad, as in the case when domestic plant costs are sunk, represent a powerful centripetal force and thus should be taken into account when assessing the probability that tighter mitigation measures unilaterally adopted will induce domestic firms to move production abroad. The key role of asymmetry in plant costs instead does not seem to be fully acknowledged in the “carbon leakage” debate currently undergoing in the EU.

Moreover, we can restrict the set of feasible outcomes, ruling out the possibility that some forms of relocation may become an equilibrium location strategy. We find that:

Proposition V *If fixed plant costs are higher when investing abroad, with low transport costs ($s < (t_I - t_H)$) partial relocation is never an optimal strategy, while with high transport costs ($s > (t_I - t_H)$) total relocation is never an optimal strategy.*

²⁹ A proof is available on request from the authors.

³⁰ The conclusions may be easily extended to $G_{1,f} > G_{1,h}$ with $G_{i,h} > 0$.

Proof:

It is easily found that

$$\hat{\pi}_1^{PR} - \hat{\pi}_1^{TR} = \frac{4}{9b} [s - (t_I - t_{II})] (a - c - t_I) \quad (17)$$

Thus $\text{sign}(\hat{\pi}_1^{PR} - \hat{\pi}_1^{TR}) = \text{sign}(s - (t_I - t_{II}))$ □

We then find that in the low transport costs scenario the only feasible outcomes are no relocation and total relocation, while in the high transport costs scenario the only feasible outcomes are no relocation and partial relocation.

4.4 Market size and plant costs asymmetry ($a_I > a_{II}$, $b_I < b_{II}$, $G_{1,f} > G_{1,h}$ or $G_{i,h}$ sunk).

Let us consider both asymmetries jointly, and assume that at the same time country *I* is larger and that firm 1 faces higher fixed plant costs in country *II*, such as when the economic life of the home plant has not reached termination and thus the domestic plant costs are sunk ($G_{i,h} = 0$). In this scenario we find:

$$\hat{\pi}_1^{NR} - \hat{\pi}_1^{TR} = \frac{4}{9} \left\{ s \left[\frac{A_I - t_I}{b_I} - \frac{A_{II} - t_I}{b_{II}} \right] - (t_I - t_{II}) \left[\frac{A_I - t_I}{b_I} + \frac{B_{II} - t_I - s}{b_{II}} \right] + \frac{s^2}{b_{II}} \right\} + G_{1,f} \quad (18)$$

We thus have three centripetal forces (market asymmetry effect, lower competition effect and plant cost asymmetry effect) opposed to the centrifugal impact of the asymmetric climate policy on the firm's location decision. Thus the forces discouraging the firm from moving production abroad are stronger: in other words the range of parameters for which unilateral environmental policy will result in firms relocating production abroad is further reduced.

The possible outcomes in terms of the firm's location strategy are summarized in Table 1. It is shown that in two key scenarios, which capture crucial features of the present economic reality, total relocation can be ruled out as a feasible outcome, i.e. it is never an optimal location strategy. In addition it emerges that no relocation is a feasible outcome in most cases.

Table 1 The impact of a unilateral pollution tax on the local firm's location strategy under different degrees of asymmetry

	$s < (t_I - t_{II})$	$s > (t_I - t_{II})$
Full symmetry	Total R	No R* Partial R Total R
Market size asymmetry	Total R	No R Partial R Total R
Plant costs asymmetry	No R Total R	No R Partial R
Market size & plant costs asymmetry	No R Total R	No R Partial R

Note: R = relocation

* = Not feasible if $s \leq 3(t_I - t_{II})$

5. Regions defining equilibrium outcomes in the short and long-run

The previous analysis can be reinterpreted as indicating equilibrium outcomes in two different time frames: the short/medium-term in which the existing capital stock is still operating and thus domestic plant fixed costs are sunk (plant cost asymmetry with $G_{i,h} = 0$), and the long-run in which a new plant should be established also in the domestic market, as the existing capital stock has reached its economic end of life (plant cost symmetry with $G_{i,h} = G_{i,f}$).³¹

³¹ The differences in the impact of unilateral mitigation measures between the short/medium term and the long term is underlined by OECD (2009) and Bergmann et al. (2007).

In order to clarify the economic implications of our model, we will illustrate (see Fig.1) the possible short-run and long-run equilibrium outcomes, with and without unilateral mitigation policy, depicting them in the (s, a_{II}) plane. These two parameters highlight the combined effect of transport costs (s) and market asymmetry (a_{II}) on the equilibrium location choice. The boundaries of the different regions are defined by the values of the parameters that satisfy the conditions in Appendix II, obtained from the previous analysis.

With a carbon tax equal to t_{II} in both countries (i.e. in the baseline scenario) the equilibrium outcomes are the same in the short and long-run (Fig 1.a). The boundaries between NR and PR are equal since $G_{1,h}$ does not affect this curve (Eq. (A.II.2) = Eq. (A.II.5)) and with symmetry in climate policy there is no centrifugal force sustaining a TR equilibrium (see Eq.(18)). This shows that in our model the asymmetry in climate policy is the only driver promoting the TR choice, while it is only one of the factors inducing the firm to choose PR, which is also motivated by the saving of trade costs (as shown by Eq. (14)). The effects of unilateral mitigation measures however differ according to the time horizon considered.

In the short-run, for most parameter values, the adoption by the large country of unilateral environmental measures does not lead to a change in the location choice of domestic firms, when considering industries characterized by high capital intensity (such as the pollution intensive sectors) (see Fig. 1.b).³² With very high transport costs and a large size of the foreign market we may have a shift to PR (see shaded area in Fig. 1.b), with firm 1 serving each market by local production. To summarize, after the introduction of $t_I > t_{II}$, in the short/medium-run NR is the most likely outcome. If a change in location strategy takes place it will be a shift not to TR but to PR, which however requires extreme values of s and a_{II} .

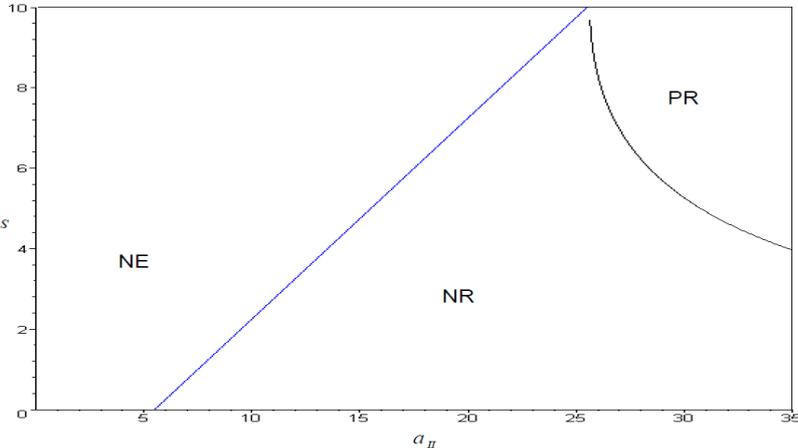
The effect of unilateral climate policy in the long-run (Fig. 1.c) presents some major dissimilarities. The main difference is that TR becomes a feasible outcome for a large set of parameters. If we are in the low transport cost scenario ($s < (t_I - t_{II})$),³³ TR

³² By restricting the parameter range to values such that $\hat{q}_{1,II}^{NR} > 0$, we are ignoring the increase in the NE (no export) region.

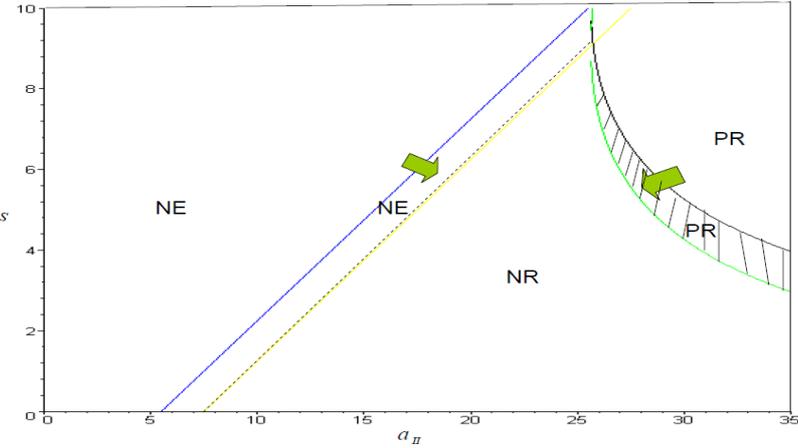
³³ That is below the horizontal line which indicates $s = (t_I - t_{II})$.

Figure 1: The effect of unilateral environmental policy on the equilibrium outcome (regions drawn for $a_I = 36$, $b_I = 2$, $b_{II} = 3$, $c = 5$, $t_{II} = 0.5$, $F = 10$)

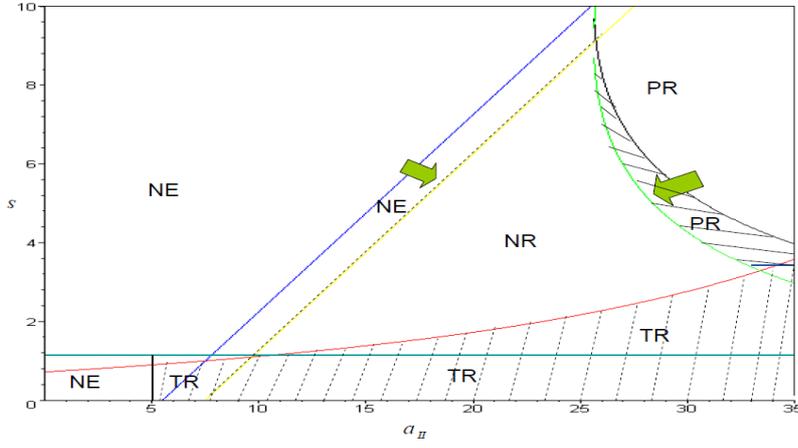
1.a *Baseline scenario* ($t_I = t_{II} = 0.5$; either $G_{i,h} = 0, G_{i,f} = 15$ or $G_{i,h} = G_{i,f} = 15$)



1.b *Short /medium-term scenario* ($t_I = 1.5$; $G_{i,h} = 0$, $G_{i,f} = 15$)



1.c *Long-term scenario* ($t_I = 1.5$; $G_{i,h} = G_{i,f} = 15$)



Note: NE=no export; NR=no relocation; PR= partial relocation; TR= total relocation

will always be the equilibrium outcome (see also Tab. 1, with plant symmetry). In the high transport cost case ($s > (t_I - t_{II})$), all three outcomes are feasible, and Fig. 1.c helps us in identifying under which conditions each outcome is most likely. We may note that market asymmetry plays a major role in determining the equilibrium location choice, with a large market asymmetry pushing towards the NR equilibrium also in the long-run (as suggested by Prop. III).

Furthermore, *ceteris paribus*, there is no additional incentive to shift to PR in the long-run as compared to the short/medium-term (the PR boundary shifts of an equal amount in Fig. 1.b and 1.c). However as country II size increases overtime, PR will become a more likely outcome for reasons independent from the unilateral carbon tax.

6. The impact of unilateral climate policy on welfare

Country I welfare (\hat{W}_I^n), after the imposition of the more stringent carbon tax, is defined as the sum of consumers surplus ($C\hat{S}_I^n$), domestic firm's global profits ($\hat{\pi}_1^n$),³⁴ government revenue generated by the pollution tax (\hat{T}_I^n) and the environmental damage (\hat{D}^n) which is strictly convex in world production,³⁵ with $n \in \{NR, PR, TR\}$. Welfare in the baseline scenario (in which t_{II} is the common price of emissions in both areas and both firms are exporting from their respective home market) is denoted by \tilde{W}_I . The social welfare function after the imposition of the stricter carbon tax is thus given by:

$$\hat{W}_I^n = C\hat{S}_I^n + \hat{\pi}_1^n + \hat{T}_I^n - \frac{\gamma_I}{2}(Q_w^n)^2 \quad (19)$$

The impact of an unilateral climate policy on the country adopting the measures (country I) is evaluated by comparing welfare after and before the introduction of the stricter carbon tax, that is ($\hat{W}_I^n - \tilde{W}_I$). This variation captures both the effect of a rise in country I's pollution tax and, if that is the case, of a change in the market structure due to a strategy shift. Fig. 1 allows us to identify in which settings each of the three equilibrium outcomes are likely to prevail, both in the short and in the long-run. The emission leakage, i.e. the environmental effectiveness of the unilateral mitigation measures, is here assessed in terms of the impact of the policy on world production and

³⁴ It is assumed that foreign profits are fully repatriated.

³⁵ The emission coefficient is set equal to 1, see p. 10.

thus on the global level of emissions.³⁶ The job leakage, which is not explicitly considered in the welfare function, is indirectly captured by the change in the carbon tax revenue, as both phenomena depend on the fall in the domestic production level.

6.1 The NR equilibrium outcome

With the adoption of unilateral environmental measures in country *I*, no change in the location strategy of local firms is the most likely outcome in the short-medium run in the case of capital intensive sectors (see Fig. 1), and may also be the equilibrium outcome in the long-run with a large market asymmetry and high transport costs.

The unilateral mitigation measure, when firm 1 location strategy does not change, leads to a fall in world production and thus emissions, although part of the contraction in domestic production is compensated by a rise in foreign output.³⁷ In fact we have:

$$(\hat{Q}_w^{NR} - \tilde{Q}_w) = -\left[\frac{t_I - t_{II}}{3b_I} + \frac{t_I - t_{II}}{3b_{II}} \right] < 0 \quad (20)$$

In this scenario, the impact of the unilateral policy on consumers' aggregate welfare is positive. Consumers' aggregate welfare (see Cole et al., 2009, p. 1242) is given by the sum of consumers' surplus and pollution tax revenues, less the damage from pollution. Here we assume that the revenue of the pollution tax is 100% returned to the taxpayers.³⁸ Although consumers' surplus narrowly defined falls, for sufficiently low values of t_{II} , the carbon tax revenue increase is greater than the fall in consumers' surplus, since under rather general conditions (see Appendix III):

$$(C\hat{S}_I^{NR} - C\tilde{S}_I) + (\hat{T}_I^{NR} - \tilde{T}_I) = \frac{t_I - t_{II}}{6} \left[\frac{2A_I - 11t_I - 3t_{II} + 8s}{3b_I} + \frac{6(A_{II} - 2t_I - t_{II} - 2s)}{3b_{II}} \right] > 0 \quad (21)$$

Furthermore, pollution damage decreases since (see Appendix III):

³⁶ As the measure of carbon leakage suggested by IPCC (2007) (see note 2) is not easily quantifiable in the PR and TR cases, we adopted a simpler indicator –the impact on world emissions– which likewise accounts for the variation of emissions in both markets.

³⁷ The rise in foreign production is equal to half the fall in domestic output.

³⁸ World Bank (2008) p.110 indicates that national policies in this regard differ. Revenue from the German ecotax are almost fully returned to taxpayers while Danish carbon tax revenues from industry are entirely recycled in that sector. On revenue recycling, see also Bergmann et al. (2007), p. 80, OECD (2009), p. 35.

$$\begin{aligned}
(\hat{D}_I^{NR} - \tilde{D}_I) = & \\
& -\frac{\gamma_I}{6}(t_I - t_{II})\left(\frac{1}{b_I} + \frac{1}{b_{II}}\right)\left[\frac{4A_I - t_I - 3t_{II} - 2s}{3b_I} + \frac{4A_{II} - t_I - 3t_{II} - 2s}{3b_{II}}\right] < 0
\end{aligned} \tag{22}$$

The local firm's profits instead diminish in both markets, as

$$(\hat{\pi}_I^{NR} - \tilde{\pi}_I) = -\frac{4}{9}(t_I - t_{II})\left[\frac{(A_I - t_I + s)}{b_I} + \frac{(A_{II} - t_I - 2s)}{b_{II}}\right] < 0 \tag{23}$$

The previous results allow us to state that:

Proposition VI *The introduction of $t_I > t_{II}$, when firm 1 location strategy does not change, leads to a fall in world emissions, a rise in consumers' aggregate welfare in country I, and a decrease in the local firm's global profits.*

As to the overall effect on country I welfare,³⁹ if we consider only one source of market asymmetry ($a_I > a_{II}$ while $b_I = b_{II} = b$), we obtain:

$$\begin{aligned}
(\hat{W}_I^{NR} - \tilde{W}_I) > 0 \text{ iff} \\
2\gamma_I(4A_I + 4A_{II} - 2t_I - 6t_{II} - 4s) > b(6A_I + 2A_{II} + 7t_I + 9t_{II} - 4s)
\end{aligned} \tag{24}$$

where γ_I represents the society's assessment of the disutility of pollution. As the LHS term in parenthesis in Eq. (24) is smaller than the RHS term in parenthesis, $2\gamma_I > b$ is a necessary but not sufficient condition for a net positive impact on welfare. If $\gamma_I = 0$, the overall impact is negative, that is the negative effect on firms prevail on the positive effect on consumers.

To summarize, an unilateral climate policy, when it does not induce a change in location strategy, may rise the welfare of the country implementing it by leading to a fall in global emissions and rising consumers aggregate welfare, although the local firm's profits decrease. This is the case also in the absence of technological innovation (not contemplated in our model) which would make condition (24) less restrictive. A positive net impact on welfare of the unilateral mitigation policy requires that a high

³⁹ The full expression of the change in welfare is reported in Appendix III.

importance is assigned by the national community to the environmental damage (i.e. that the value of γ_I is high).

6.2 The PR equilibrium outcome

Figures 1b and 1c show that a shift to partial relocation is possible only if we are in the high transport cost scenario (thus $s > (t_I - t_{II})$) and the size of the foreign market is large and thus market asymmetry is limited. It also requires that the foreign plant fixed costs are not too high.

If unilateral measures lead to partial relocation of domestic production, global emissions may rise as the fall in domestic production may be more than compensated by foreign production expansion. This will depend on the degree of market asymmetry, since:

$$(\hat{Q}_W^{PR} - \tilde{Q}_W) = - \left[\frac{t_I - t_{II}}{3b_I} - \frac{s}{3b_{II}} \right]. \quad (25)$$

The condition for global pollution to rise is $\frac{s}{t_I - t_{II}} > \frac{b_{II}}{b_I}$, which is not too restrictive as PR requires moderate market asymmetry.⁴⁰ By comparing Eq.s (20) and (25) we find that the emission leakage is always greater with PR than with NR.

The sign of the impact on consumers' aggregate welfare is undetermined. The sum of consumers' surplus and the carbon tax revenue is given by

$$(C\hat{S}_I^{PR} - C\tilde{S}_I) + (\hat{T}_I^{PR} - \tilde{T}_I) = \frac{t_I - t_{II}}{6} \left[\frac{2A_I - 11t_I - 3t_{II} + 8s}{3b_I} \right] - t_{II} \left[\frac{(A_{II} - t_{II} - 2s)}{3b_{II}} \right] \quad (26)$$

which for $t_{II} = 0$ is positive, although lower than in the no strategy shift case.

However, as world production may increase, and thus pollution damage may grow, we cannot say what will be the overall impact on consumer aggregate welfare.

The change in damage is given by:

$$(\hat{D}_I^{PR} - \tilde{D}_I) = \frac{\gamma_I}{6} \left[\frac{s}{b_{II}} - \frac{(t_I - t_{II})}{b_I} \right] \left[\frac{4A_I - t_I - 3t_{II} - 2s}{3b_I} + \frac{4A_{II} - 4t_{II} - s}{3b_{II}} \right] \quad (27)$$

⁴⁰ With $b_I = b_{II} = b$, as we are in the high transport cost scenario, global emissions will certainly rise.

which, with $b_I = b_{II} = b$, is positive as under this assumption overall emissions increase.

Firm 1 profits fall in the domestic market but rise abroad, furthermore the firm faces additional fixed costs. We thus have:

$$(\hat{\pi}_1^{PR} - \tilde{\pi}_1) = \frac{4}{9} \left[s \frac{(A_{II} - t_{II} - s)}{b_{II}} - (t_I - t_{II}) \frac{(A_I - t_I + s)}{b_I} \right] - G_{1,f} \quad (28)$$

As to the overall welfare impact, assuming $b_I = b_{II} = b$ and $t_{II} = 0$ we have:

$$(\hat{W}_I^{PR} - \tilde{W}_I) = -\frac{1}{18b} \left\{ [3t_I(2A_I + t_I) - 8s(A_{II} - s)] + \frac{\gamma_I}{b} [(s - t_I)(4A_I + 4A_{II} - t_I - 3s)] \right\} - G_{1,f} \quad (29)$$

Therefore the sufficient condition for a fall in welfare becomes:

$$b[3t_I(2A_I + t_I) - 8s(A_{II} - s)] + \gamma_I [(s - t_I)(4A_I + 4A_{II} - t_I - 3s)] > 0 \quad (30)$$

As expected, a high value of γ_I enhances the negative effect on welfare (since with $b_I = b_{II} = b$ world pollution increases).

To summarize, an unilateral environmental policy shifting the equilibrium to PR may lead to higher global emissions. It is thus possible that, when transport costs are very high and the market asymmetry is limited, an unilateral carbon tax may fail to achieve its primary task. In addition, the carbon tax revenue is also limited, as now production in country I is aimed only to serve the local market, thus the sign of consumer aggregate welfare is undetermined. The model shows that, contrary to what generally stated,⁴¹ transport costs may rise the probability of carbon leakage. Although transport costs favour domestic production to serve the home market, they may also encourage the domestic producer to supply the foreign market via FDI instead of export, thus possibly leading to a high degree of carbon leakage.

6.3 The TR equilibrium outcome

Figures 1.b and 1.c show that total relocation of production abroad is an unlikely outcome in the short-term, while in the long-term this is the outcome for any degree of market asymmetry if we have low transport costs.

⁴¹ IPCC (2007) chapter 11, p.666 states that transport costs favour local production and thus decrease the probability of carbon leakage.

When the equilibrium shifts to TR, global emissions decrease as world production falls.⁴² We have:

$$(\hat{Q}_W^{TR} - \tilde{Q}_W) = -\left[\frac{s}{3b_I} - \frac{s}{3b_{II}}\right] < 0 \quad (31)$$

Consumer aggregate welfare is likely to fall. As all production is moved abroad, the change in carbon tax revenue is negative. We thus obtain:

$$\begin{aligned} (C\hat{S}_I^{TR} - C\tilde{S}_I) + (\hat{T}_I^{TR} - \tilde{T}_I) = \\ -\frac{s}{6}\left[\frac{4A_I - 4t_{II} - 3s}{3b_I}\right] - t_{II}\left[\frac{(A_I - t_{II} + s)}{3b_I} + \frac{(A_{II} - t_{II} - 2s)}{3b_I}\right] < 0 \end{aligned} \quad (32)$$

while the change in damage is given by

$$(\hat{D}_I^{TR} - \tilde{D}_I) = -\frac{\gamma_I}{6}s\left(\frac{1}{b_I} - \frac{1}{b_{II}}\right)\left[\frac{4A_I - 4t_{II} - 3s}{3b_I} + \frac{4A_{II} - 4t_{II} - s}{3b_{II}}\right] < 0 \quad (33)$$

Thus, if we consider $b_I = b_{II} = b$, then $(\hat{D}_I^{TR} - \tilde{D}_I) = 0$ and consumers' aggregate welfare will certainly decrease, given Eq. (32).

Variable profits due to domestic sales fall more than the increase in variable profits due to foreign sales, and furthermore there may be an increase in fixed costs. We have:

$$(\hat{\pi}_1^{TR} - \tilde{\pi}_1) = -\frac{4}{9}s\left[\frac{(A_I - t_{II})}{b_I} - \frac{(A_{II} - t_{II} - s)}{b_{II}}\right] - (G_{1,f} - G_{1,h}) < 0 \quad (34)$$

The overall effect on welfare, when $b_I = b_{II} = b$ and thus $(\hat{D}_I^{TR} - \tilde{D}_I) = 0$, is equal to:

$$\begin{aligned} (\hat{W}_I^{TR} - \tilde{W}_I) = \\ -\frac{1}{18b}\left[s(12A_I - 8A_{II} + 5s - 4t_{II}) + 6t_{II}(A_I + A_{II} - 2t_{II} - s)\right] - (G_{1,f} - G_{1,h}) < 0 \end{aligned} \quad (35)$$

Motta and Thisse (1994) found that welfare could increase with the introduction of an unilateral carbon tax leading to TR, in contrast with our findings. However their model differs from ours in various respects. Firstly, they consider local instead of global pollution. In our model, damage (which is related to global output) either does not

⁴² If we consider only one source of market asymmetry, setting $b_I = b_{II}$, the level of world production does not change.

decrease (when considering $b_I = b_{II} = b$) or decreases less than in the local pollution case. Furthermore in their analysis, before t_I is introduced, there is no price of emissions in country I , and thus when production shifts abroad, there is no loss of carbon tax revenue. That too implies a more positive effect on country I welfare.

To summarize, an unilateral environmental policy, when it does induce a shift of equilibrium to total relocation, may have some effect in containing global emissions. Furthermore carbon revenue falls substantially as all domestic production is moved abroad, and as a consequence consumers' aggregate welfare shrinks. Thus the net effect on welfare is likely to be negative. This is the worst scenario in terms of the job leakage as all production will be undertaken in the foreign market.

7. Implications as to carbon leakage provisions in EU and US climate policies

The design of climate policy both in the US and EU has been heavily influenced by fears of emission and job leakage, as this has become a major political issue across the Atlantic. In both cases special provisions have been introduced in favour of sectors identified as vulnerable.

US legislation on climate change policy is still under examination. The American Clean Energy and Security Act known as the Waxman-Markey Bill, was approved by the House of Representatives in June 2009 (HR 2454), and the Kerry-Lieberman American Power Act has been presented at the Senate in May 2010. The Waxman-Markey Bill⁴³ establishes quantitative criteria for identifying which manufacturing industries are “energy-intensive and trade-exposed (EITE)”, thus presumably eligible for special provisions. They are: 1) energy intensity (or carbon intensity) is at least 5 percent and trade intensity is at least 15 percent⁴⁴ or 2) energy intensity (or carbon intensity) is at least 20 percent, regardless of the trade intensity.⁴⁵

Two sets of provisions to moderate competitiveness and leakage impacts are considered. To start with, free emission allowances will be allocated (or allowance rebates provided) to EITE sectors, by using a continuously updating output-based

⁴³ As the Kerry-Lieberman Bill is still a draft, we will focus on HR 2454.

⁴⁴ See US EPA (2009), p. 8, for the definition of industry's energy intensity etc..

⁴⁵ Out of the nearly 500 six-digit manufacturing industries considered, 44 would be identified as EITE under H.R. 2454 (see US EPA, 2009, pp. 2, 9.).

formula⁴⁶ (thus considering current production) (see US EPA, 2009, p. 30). This measure is guaranteed up to 2025 and will be phased out by 2035. The other provision consists in “border tax adjustments”, i.e. border taxes on carbon intensive imports from countries without comparable climate policy starting in 2020 (see US EPA, 2009, p. 30; Carbon Trust, 2009; Dröge, 2009).

A broader set of criteria have been adopted by the EU Directive 2009/29/EC⁴⁷ to identify sectors “deemed to be exposed to a significant risk of carbon leakage”. They are: 1) additional CO₂ costs as a proportion of gross value added of at least 5% **and** trade intensity with third countries exceeding 10%; or 2) additional CO₂ costs as a proportion of gross value added of at least 30% regardless of trade intensity; or 3) trade intensity with third countries exceeding 30% regardless of carbon intensity. The third criterion considerably enlarges the range of sectors included. Out of 258 manufacturing sectors examined at the 4-digit NACE level, 147 were found to be at significant risk of carbon leakage (117 of which due to the trade intensity criterion).⁴⁸ The sectors at risk of carbon leakage are estimated to account for around 77% of the total emissions from manufacturing industry in the EU ETS, while EITE account for almost half of US manufacturing GHG emissions.⁴⁹

The EU Directive provides that installations in vulnerable sectors shall receive 100% of allowances free, through an allocation system based on ex-ante product-specific benchmarks.⁵⁰ An installation will thus receive a fixed free amount of allowances, depending on the relevant benchmark and its historical production level. Each benchmark is calculated by considering the average performance of the 10% most efficient installations in the Community that produce the given product, to ensure that producers have a strong incentive to reduce emissions.⁵¹ This provision is complemented by plant closure rules (with withdrawn allowances if a facility cease or

⁴⁶ In each year, rebates for direct emissions would be calculated by multiplying an eligible entity’s average output in the two prior years by the average direct GHG emission intensity of the sector. See US EPA (2009), p.30.

⁴⁷ The 2009 Directive revised the initial EU ETS 2003 Directive.

⁴⁸ Bergman, H. (2009), ‘Sectors deemed to be exposed to a significant risk of carbon leakage –outcome of the assessment’ DG Environment C2, European Commission, http://ec.europa.eu/environment/climat/emission/pdf/wg3_16_sep_presentation.pdf

⁴⁹ The list of carbon leakage sectors was notified by the Commission in December 2009. The assessment was performed at the NACE 4-digit level, considering an average carbon price of €30 per ton of CO₂, as indicated in the Directive. See FAQ in http://ec.europa.eu/environment/climat/emission/index_en.htm (carbon leakage). For the US figure see EPA (2009), p. 2.

⁵⁰ The Commission will determine the benchmarks by 31 December 2010.

⁵¹ The free allowances cover the full direct costs, but not the indirect costs which may however be compensated by each relevant Member State (art 10a(6)).

partially cease operations). Furthermore, a new entrant or an installation undertaking “significant extension of activity” will also receive free allowances. The Directive has not ruled out the possibility of imposing border tax adjustments.⁵²

The attempt to moderate the competitiveness-driven job leakage has influenced the allocation rules in the Waxman-Markey Bill even more than in the EU Directive, at the cost of creating a less cost-efficient cap and trade system. The US proposed allocation mode amounts to an output subsidy which decreases the marginal (and unit variable) cost of US production, thus lowering the incentive to both partial and total relocation. However this system “will not allow the full CO₂ price signal to diffuse through product prices” (Reinaud, 2008, p. 84) as firms are not confronted with an opportunity cost for the permits. If a firm reduces production it does not enjoy extra permits to sell into the market; it will instead receive a smaller amount of allowances/rebates since these are linked to current output. The US system thus hampers demand reduction of CO₂ intensive products and possibly innovation. On the contrary the approach adopted by the EU, by fixing before the trading period the amount of free allowances allocated, creates an opportunity costs for the permits and thus introduces a visible CO₂ price signal. Fixed free allocations represent a lump sum transfer to producers and, when complemented by new entrant reserve and closure rules, may affect firms’ location decisions. The EU system can thus be seen as leading to an increase in the fixed cost of relocation, since by shifting production abroad firms renounce to a lump sum transfer. We saw (Eq.s (14), (18)) that the relocation of production decision is influenced also by fixed costs considerations.

As to border tax adjustment on imports, which plays an important role in the US but not in the EU legislation, our model suggests an additional reason for such measure not to be adopted. An import tax does not affect the incentive to partially relocate production, which emerges as the most likely location strategy shift induced by unilateral climate policy. This is the case since, with partial relocation, the domestic producers continue to serve the national market from the home plant. A large number of other important economic problems discouraging the adoption of a border tax adjustments on imports have been discussed in the literature, such as the risk of trade disruption due to trade retaliation, difficulties in defining which category of products

⁵² Art 10b of EU Directive 2009/29/EC establishes that by 30 June 2010 the Commission should submit a report suggesting appropriate proposals for sectors at risk of carbon leakage which may include free allowances and border carbon taxes.

within a given sector to select and in measuring and monitoring, potentially large administrative costs, etc. (OECD, 2009, p. 37).

To sum up, climate policy in both regions has been heavily shaped by competitiveness-driven carbon leakage considerations, due to strong pressures from industry groups. The EU allocation mode seems to strike a better balance between the aim of moderating relocation-driven carbon leakage and the cost-effectiveness of the policy. On the other hand, the EU criteria for identifying vulnerable sectors are certainly not restrictive enough, and much broader than in the US case.

8. Conclusions and future research

The aim of the paper is to show that the FDI perspective may contribute to the pollution haven and “carbon leakage” debates, calling attention on how plant fixed costs and transport costs, interacting with relative market size, affect the probability of shifts in local firms’ international location strategy, when a country (or a group of countries) adopts unilateral mitigation measures.

It is shown that the fear of total production relocation is highly exaggerated in the pollution haven and “carbon leakage” literature and in the public debate, at least when considering the short/medium-run, that is when domestic plant costs are sunk. This does not always represent a narrow time span, as the economic life of plants in pollution-intensive sectors may extend to over 30 years.⁵³ When domestic plant costs are sunk, total relocation cannot be an optimal strategy in the high transport costs scenario, which is the most plausible case for pollution-intensive sectors. Furthermore, numerical simulations tend to exclude the possibility of a total relocation equilibrium also in the case of low transport costs. If the home plant fixed costs are not sunk (which may represent the long-term), a pronounced market asymmetry associated to high transport costs may explain why an unilateral increase in the stringency of environmental policy by the larger area may not result in local firms moving all production abroad. However if the asymmetry in environmental policy is expected to persist over the long run and the cooperating area does not enjoy a large size advantage *vis-à-vis* the rest of the world, total relocation may become an equilibrium outcome also with high transport costs. Nevertheless, this outcome would require stable

⁵³ See footnote 16.

expectations as to the regulatory regime and future market conditions, which is not a likely scenario in the present context of climate policy uncertainty.

In the short/medium-term, if there is a location strategy shift, this will take the form of partial relocation of production. That is, firms from the region with the more stringent environmental measures may start producing also abroad, instead of serving the foreign market via export. We found that, with partial relocation, the global level of pollution may rise, depending on the extent of the market asymmetry, and thus unilateral environmental policy may fail to achieve its primary aim. Nevertheless, we should consider that the main driver of the decision to produce also in other major areas is represented by the fast growth of foreign markets.⁵⁴ Therefore, the stricter pollution measures are likely to accelerate a decision which would be taken in any case later on. The model shows that, contrary to expectations, transport costs may induce carbon leakage, by favouring partial relocation of production.

As to the welfare impact, an unilateral environmental policy not leading to a change in location strategy may rise welfare, by bringing about a fall in global emissions and rising consumers' aggregate welfare, although local firms' profits decrease. In order to have a positive net effect, a public opinion seriously interested in the solution of the environmental problem, and thus assigning great importance to a fall in pollution damage, is required. On the other hand, the net effect on welfare of unilateral measures is likely to be negative when the policy leads to partial or total relocation. Thus, the temporal dimension of the asymmetry in environmental policy (i.e. if it is a structural or transient scenario as other countries will follow) and the relative size of the cooperating area emerge as critical factors influencing the possibility to implement successfully more restrictive environmental measures.

The attempt to moderate the risk of relocation-driven carbon leakage is indicated as a major objective of both EU and US climate policy. We found however that some of the measures considered do not create the right incentives as they are designed to deter total relocation of production but not partial relocation, which instead emerged as the most likely location strategy shift induced by unilateral climate policy. For instance the "border tax adjustments" on carbon intensive imports, proposed by the US Waxman-Markey Bill and considered also by the European Directive, may be effective when

⁵⁴ The Financial Times, December 30 2009, p. 15 "Cement makers seek to spread risk", indicates that the shift of growth from mature to emerging construction markets is a key reason why both Lafarge and Holcim have both sought to begin producing also in China.

firms plan to relocate all production abroad and serve the home market from the foreign plant, but would not create any centripetal incentive if firms plan to serve each market via local production. Alternative measures should be designed, aimed on one hand to reduce the incentive to produce in both areas and on the other to limit the possible negative impact of a location strategy shift on the global level of emissions.

In order to address this important issue, it is necessary to enrich the analysis by accounting for technological differences between countries, which implies that emission coefficients vary across regions. The assumption of technological similarity across countries and firms is a limit of our analysis, leading us to overestimate the negative impact on global pollution due to a location strategy shift. Our next step will be to extend the model by considering technological asymmetries between firms operating in different areas and the role of multinational companies in the international transfer of green technologies.

Appendix I

The objective functions in the different scenarios are:

Case I: no relocation, that is (NR)

$$\begin{aligned} \pi_1^{NR} = & (a_I - b_I q_{1,I} - b_I q_{2,I}^e) q_{1,I} + (a_{II} - b_{II} q_{1,II} - b_{II} q_{2,II}^e) q_{1,II} - c q_{1,I} \\ & - (c + s) q_{1,II} - t_I (q_{1,I} + q_{1,II}) - F - G_{1,h} \end{aligned} \quad (AI.1)$$

$$\begin{aligned} \pi_2^{NR} = & (a_I - b_I q_{1,I}^e - b_I q_{2,I}) q_{2,I} + (a_{II} - b_{II} q_{1,II}^e - b_{II} q_{2,II}) q_{2,II} - (c + s) q_{2,I} \\ & - c q_{2,II} - t_{II} (q_{2,I} + q_{2,II}) - F - G_{2,h} \end{aligned} \quad (AI.2)$$

Case II: partial relocation, that is (PR)

$$\begin{aligned} \pi_1^{PR} = & (a_I - b_I q_{1,I} - b_I q_{2,I}^e) q_{1,I} + (a_{II} - b_{II} q_{1,II} - b_{II} q_{2,II}^e) q_{1,II} - c (q_{1,I} + q_{1,II}) \\ & - t_I q_{1,I} - t_{II} q_{1,II} - F - G_{1,h} - G_{1,f} \end{aligned} \quad (AI.3)$$

$$\begin{aligned} \pi_2^{PR} = & (a_I - b_I q_{1,I}^e - b_I q_{2,I}) q_{2,I} + (a_{II} - b_{II} q_{1,II}^e - b_{II} q_{2,II}) q_{2,II} - (c + s) q_{2,I} \\ & - c q_{2,II} - t_{II} (q_{2,I} + q_{2,II}) - F - G_{2,h} \end{aligned} \quad (AI.4)$$

Case III: total relocation, that is (TR)

$$\begin{aligned} \pi_1^{TR} = & (a_I - b_I q_{1,I} - b_I q_2^e) q_{1,I} + (a_{II} - b_{II} q_{1,II} - b_{II} q_2^e) q_{1,II} - (c + s) q_{1,I} - c q_{1,II} \\ & - t_{II} (q_{1,I} + q_{1,II}) - F - G_{1,f} \end{aligned} \quad (AI.5)$$

$$\begin{aligned} \pi_2^{TR} = & (a_I - b_I q_{1,I}^e - b_I q_{2,I}) q_{2,I} + (a_{II} - b_{II} q_{1,II}^e - b_{II} q_{2,II}) q_{2,II} - (c + s) q_{2,I} \\ & - c q_{2,II} - t_{II} (q_{2,I} + q_{2,II}) - F - G_{2,h} \end{aligned} \quad (AI.6)$$

Appendix II

Short-term boundary conditions ($G_{i,h} = 0$)

$$\hat{\pi}_1^{NR} - \hat{\pi}_1^{TR} = \frac{4}{9} \left\{ s \left[\frac{A_I - t_I}{b_I} - \frac{A_{II} - t_{II}}{b_{II}} \right] - (t_I - t_{II}) \left[\frac{A_I - t_I}{b_I} + \frac{A_{II} - t_{II} - s}{b_{II}} \right] + \frac{s^2}{b_{II}} \right\} + G_{1,f} \quad \text{AII.1 (see Eq.18)}$$

$$\hat{\pi}_1^{NR} - \hat{\pi}_1^{PR} = G_{1,f} - \frac{4}{9} [s + (t_I - t_{II})] \frac{A_{II} - t_{II} - s}{b_{II}} = 0 \quad \text{AII.2 (see Eq.14)}$$

$$\hat{\pi}_1^{PR} - \hat{\pi}_1^{TR} = \frac{4}{9} [s - (t_I - t_{II})] \frac{A_I - t_I}{b_I} = 0 \quad \text{AII.3 (see Eq. 17)}$$

Long-term boundary conditions ($G_{i,h} = G_{i,f}$)

$$\hat{\pi}_1^{NR} - \hat{\pi}_1^{TR} = \frac{4}{9} \left\{ s \left[\frac{A_I - t_I}{b_I} - \frac{A_{II} - t_{II}}{b_{II}} \right] - (t_I - t_{II}) \left[\frac{A_I - t_I}{b_I} + \frac{A_{II} - t_{II} - s}{b_{II}} \right] + \frac{s^2}{b_{II}} \right\} \quad \text{AII.4 (see Eq.18)}$$

$$\hat{\pi}_1^{NR} - \hat{\pi}_1^{PR} = G_{1,f} - \frac{4}{9} [s + (t_I - t_{II})] \frac{A_{II} - t_{II} - s}{b_{II}} = 0 \quad \text{AII.5 (see Eq.14)}$$

$$\hat{\pi}_1^{PR} - \hat{\pi}_1^{TR} = \frac{4}{9} [s - (t_I - t_{II})] \frac{A_I - t_I}{b_I} - G_{1,h} = 0 \quad \text{AII.6 (see Eq. 10)}$$

with $A_i = (a_i - c)$.

Appendix III

III.1 We have that under rather general conditions:

$$(C\hat{S}_I^{NR} - C\tilde{S}_I) + (\hat{T}_I^{NR} - \tilde{T}_I) = \frac{t_I - t_{II}}{6} \left[\frac{2A_I - 11t_I - 3t_{II} + 8s}{3b_I} + \frac{6(A_{II} - 2t_I - t_{II} - 2s)}{3b_{II}} \right] > 0 \quad \text{AIII.1}$$

In fact, if $t_{II} = 0$, the second term in square brackets is positive since $A_{II} - 2t_I - 2s > 0$ for $q_{I,II}^{NR} = \frac{A_{II} - 2t_I - 2s + t_{II}}{b_{II}} > 0$. If $t_{II} = 0$, the first term is given by $2A_I - 11t_I + 8s$. With $s > t_I$, $2A_I - 11t_I + 8s > 2A_I - 3t_I$, and $2A_I - 3t_I > A_{II} - 2t_I - 2s > 0$. If $s < t_I$, the sufficient condition for $2A_I - 11t_I + 8s > 0$ becomes $\frac{7}{12}t_I \leq s$, under which $2A_I - 11t_I + 8s > 2(A_{II} - 2t_I - 2s) > 0$.

III.2 As to pollution damage:

$$(\hat{D}_I^n - \tilde{D}_I) = \frac{\gamma}{2} \left[(\hat{Q}_w^n)^2 - (\tilde{Q}_w)^2 \right] = \frac{\gamma}{2} \left[(\hat{Q}_w^n + \tilde{Q}_w)(\hat{Q}_w^n - \tilde{Q}_w) \right] \quad \text{AIII.2}$$

with $n \in \{NR, PR, TR\}$. It follows that $sign(\hat{D}_I^n - \tilde{D}_I) = sign(\hat{Q}_w^n - \tilde{Q}_w)$.

III.3 The full expressions of the net welfare effect with the NR equilibrium is given by:

$$(\hat{W}_I^{NR} - \tilde{W}_I) = \frac{(t_I - t_{II})}{18} \left\{ \begin{array}{l} \gamma \left(\frac{1}{b_I} + \frac{1}{b_{II}} \right) \left[\frac{4A_I - t_I - 3t_{II} - 2s}{b_I} + \frac{4A_{II} - t_I - 3t_{II} - 2s}{b_{II}} \right] \\ - \left[\frac{6A_I + 3t_I + 3t_{II}}{b_I} + \frac{4A_{II} + 4t_I + 63t_{II} - 4s}{b_{II}} \right] \end{array} \right\} \quad \text{AIII.3}$$

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