Relocation in presence of polluting and heterogeneous technologies

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Abstract. This paper develops a simple partial equilibrium model with two regions, North and South, to fathom the effects of firms' relocation in a context of international and imperfect competition. Two different production technologies are considered, a relatively clean technology and a dirty one, and the effects of relocation according to the kind of technology used by the relocated firms are determined. We consider one immobile dirty firm located in the South and two mobile firms: one relatively clean and one dirty firm. This paper demonstrates that the offshoring of a dirty firm as compared to the offshoring of a clean firm is worse for the environment, better for northern consumers, and better for the domestic profits. The results are reversed in case of reshoring.

Keywords. Relocation; Emissions tax; Trade of polluting goods; Dirty and clean production technologies; Imperfect competition.

JEL codes. L13, Q53, Q58.

1 Introduction

The relocation of companies is a particularly sensitive and topical subject,[1] and encompasses different situations. The companies in a country may change location for the first time (offshoring), and these relocated companies can relocate to their country of origin (reshoring). These two concepts were discussed in particular during the Covid-19 crisis. On the one hand, offshoring was criticized as it partly explains the difficulties in supplying strategic goods such as medicines or face masks. Offshoring can be also detrimental to a country: it leads to

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[1]According to Amiti (2005), 2,634 articles on offshoring were published in US newspapers in the first five months of 2004, about five times the amount of coverage found in a similar period in 2001.

job losses in specific sectors, especially low-skilled jobs,[2] and in specific regions,[3] and thus leads to the destruction of physical and human capital. Rising unemployment also generates costs such as unemployment benefits but also deficits in taxes and social contributions. On the other hand, reshoring is now one of the stated objectives of many developed countries. For instance, the recent 8 billion euros rescue plan for Renault requires the location of production and assembly in France for electric vehicles.[4] Reshoring makes it possible to reduce dependence on foreign countries and, conversely to offshoring, to increase the number of jobs and rebuild physical capital. This paper studies the effects of offshoring and reshoring.

This study focuses on the effects of relocation on both environment and competition, and ignores the issues of strategic dependency. Many sectors using offshoring, such as cement or steel, are characterized by polluting production processes and are oligopolistic. Offshoring can be harmful for the environment since firms that relocate in countries implementing more lenient environmental regulations, may contribute to increase emissions by producing more (see for instance Taylor (2015) and the literature on pollution havens). Moreover, in the presence of international trade and imperfect competition, relocations alter market structures and competition, and changes the exercise of market power by firms. This paper takes into account technology heterogeneity among countries and firms. More precisely, we focus on emissions intensity heterogeneity, which means that the production of one unit of the same good can generate different levels of emissions between companies. Indeed, according to Lyubich et al. (2018), to produce one dollar of output, a plant at the 10^{th} percentile of a typical industry's energy productivity distribution spends 580 percent more on energy than a plant at the 90^{th} percentile of the same industry. It therefore seems interesting to examine the effects of relocations (either offshoring or reshoring) on welfare depending on whether the technology used is environmentally-friendly or not. This study sheds some lights on the merits to retain or to attract a clean or dirty company on the territory.

We develop a simple partial equilibrium model with two regions (North and South) to fathom the effects of firms' relocation in a context of international and imperfect competition. Each region implements an emission tax, and firms produce an homogeneous polluting good consumed in each region. We consider that transporting goods from one region to another creates emissions and we consider two different production technologies, a relatively clean technology and a dirty one. The cleanliness of a firm is given by its emissions intensity, that is the number of emissions per unit produced. The southern economy is assumed to be less advanced than the northern economy where the emissions tax and the production cost are higher. These assumptions reflect the facts that the environmental awareness increases with the development, and that labour is usually more expensive in advanced economies. To sim-

[2] Many studies show that offshoring negatively affects demand for low-skilled workers (see for instance, Geishecker (2002), Wright (2014), or Feenstra and Hanson (1996)). However, Winkler (2009) reports that the effect of services offshoring in Germany was negative for the relative demand for high-skill German labour for the period 1995-2004.

[3]Using French data, Jennequin et al. (2018) shows that offshoring generates significant asymmetric shocks at the local level.

[4]Reshoring, is also a perennial subject in the US, as an illustration, on August 23 2019, Trump took to Twitter, ordering American companies to "immediately start looking for an alternative to China" and build more products in the U.S.

plify the analysis, we consider three firms: one dirty firm in the South that is not mobile, and two mobile firms, one clean firm and one dirty firm. Assuming this, there are four possible cases: the two mobile firms are located in the North, only one clean (or one dirty) firm is located in the North, and all firms are in the South. By comparing the four scenarios, we are able to study from a normative point of view the benefits and disadvantages of relocation (offshoring and reshoring). More specifically, we study how relocation affects the price, the emissions, the profits and the production. The paper shows that the offshoring of a dirty firm as compared to the offshoring of a clean firm is worse for the environment, better for northern consumers, and better for the domestic profits. On the opposite, the reshoring of a dirty firm as compared to the offshoring of a clean firm is better for the environment, worse for northern consumers, and the domestic profits.

This paper is related to the strand of literature which studies the determinants and the effects of relocation when there is pollution, trade and asymmetric environmental regulation such as Motta and Thisse (1994), Hoel (1997), Markusen et al. (1993), Greaker (2003), Petrakis and Xepapadeas (2003) and Sanna-Randaccio et al. (2017). Our paper departs from Markusen et al. (1993), Hoel (1997) and Greaker (2003) which examine how the optimal environmental policy depends on the possibility that firms may relocate. Indeed, like Motta and Thisse (1994), we consider environmental policy to be exogenous and study its effects. The closest paper to our article is Motta and Thisse (1994). The authors analyse in a context of two countries, global pollution and two firms (one in each country) how the implementation of an environmental policy in one country can lead to the relocation of the firm residing there or the opening by the latter of a subsidiary abroad. In addition, they study the welfare effects of offshoring. Our article is complementary to the latter and we consider two firms in the home country, one clean and one polluting, and we assume that pollution is global. This framework allows us to compare the effect of relocating a clean firm with the effect of relocating a polluting firm, which was impossible to study in the model developed by Motta and Thisse (1994). The other difference with this paper is that we do not consider the possibility of opening a subsidiary and only study the complete relocation of production activities. We also study the conditions under which firms relocate by considering that the two mobile firms simultaneously decide on their choice of location. Our paper complements Motta and Thisse (1994), but also Petrakis and Xepapadeas (2003) and Sanna-Randaccio et al. (2017), which determine the conditions of relocation by considering that only one firm can relocate.

The paper is structured as follows. Section 2 presents the modelling assumptions and present the four cases. Section 3 compares the different scenarios and discusses the effects of offshoring. Section 4 puts the results in perspectives and derives some policy implications. Section 5 concludes the paper.

2 The model

2.1 The set-up

The model describes the production and the trade of an homogeneous good by two countries: the country N (N denotes North) and the country S (S denotes South). In each country, there are consumers and firms respectively purchasing and producing the homogeneous good. The demand function of the good in the country l is given by $p_l = a_l - Q_l$, where a_l is the market size in country l, and Q_l the quantity consumed in country l.

Firms are assumed to compete "à la Cournot" in each market. We consider three firms: one dirty firm in the South that is not mobile, and two mobile firms.

The production of the good is polluting and generates emissions which are harmful. We consider pollution with global effects. In order to emphasize the role of technology, we consider two different production technologies: a so-called clean technology, denoted by c and a so-called dirty technology, denoted by d. Each production technology is defined by its emission intensity, which is the number of emission units generated by the production of one unit. Let μ^k be the emission intensity associated to technology k. Let us denote the emission intensity gap by $\Delta_\mu = \mu^d - \mu^c > 0$. We consider that one mobile firm is clean (it owns the clean technology) and the other mobile firm is dirty (it owns the dirty technology). Furthermore, the southern firm is also assumed to be dirty. Technological asymmetry can be explained by different research and development efforts or simply by different successes.

In each country, an emissions tax is introduced to reduce the emissions generated by the production of the goods. Let us denote $\tau_l > 0$ the emissions tax in country l. We assume that the emissions tax in the North is higher than the one in the South that is $\Delta_\tau = \tau_N - \tau_S > 0$. Indeed, developed countries are currently doing greater efforts than developing countries.

Each firm is assumed to sell on the two markets. Transportation from one country to another generates emissions with global effect and is costly. Let us assume that each unit of good transported, either from North to South or from South to North, induces γ unit of pollution emissions. Let us also assume that transportation cost does not depend on the cleanliness of the production technology. We consider a symmetric and constant unit transportation cost t in the two regions. Production of the northern clean (dirty) firm i sold in the North and in the South is respectively denoted by $r^c_{NN_i}$ and $r^c_{NS_i}$ ($r^d_{NN_i}$ and $r^d_{NS_i}$). Let us also denote $r^d_{SN_i}$ and $r^d_{SS_i}$ ($r^c_{SN_i}$ and $r^c_{SS_i}$), the production of the southern dirty (clean) firm i, sold respectively in the northern and in the southern market.

We also take into account that production costs differ between the North and the South. Let us also denote c_l the production cost in country l. We assume that the production costs are higher in the northern economy than in the southern one, that is $\Delta_c = c_N - c_S > 0$.

The mobile firms may relocate. Let us assume that clean and dirty firms have the same relocation costs. However we assume that the cost of offshoring (from the North to the South)

C^O is different from the cost of reshoring (from the South to the North) C^R.

2.2 The different scenarios

We analyze the effects of relocation by focusing on the technology used by the relocated firm. Therefore, we consider the four different cases: the two mobile firms are located in the North, only one clean (or one dirty) firm is located in the North, and all firms are in the South.

Case 1. North: one dirty and one clean firm - South: one dirty firm. The two northern firms sell in the North and in the South. In the North, one dirty firm and one clean firm coexist. They respectively solve the following problems:

$$\max_{r^d_{NS}, r^d_{NN}} \ \pi^d_N = (p_S - c_N - \tau_N\, \mu^d - t)\, r^d_{NS} + (p_N - c_N - \tau_N\, \mu^d)\, r^d_{NN}, \tag{1}$$

$$\max_{r^c_{NS}, r^c_{NN}} \ \pi^c_N = (p_S - c_N - \tau_N\, \mu^c - t)\, r^c_{NS} + (p_N - c_N - \tau_N\, \mu^c)\, r^c_{NN}. \tag{2}$$

The two northern firms have to pay the emissions tax in the North, their unit production cost is $c_N + \tau_N\, \mu^c$ for the clean firm and $c_N + \tau_N\, \mu^d$ for the dirty one, respectively. Each unit exported induces an additional transportation cost t. The southern firm solves the following problem:

$$\max_{r^d_{SS}, r^d_{SN}} \ \pi^d_S = (p_S - c_S - \tau_S\, \mu^d)\, r^d_{SS} + (p_N - c_S - \tau_S\, \mu^d - t)\, r^d_{SN}. \tag{3}$$

The unit production cost for a southern firm is $c_S + \tau_S\, \mu^d$ which consists of the production cost c_S and the cost related to the environmental tax $\tau_S\, \mu^d$. As previously, each unit exported induces an additional transportation cost t.

By calculating the first-order conditions and solving the system of equations, we obtain the productions at equilibrium, which are given by:

$$r^{d_1}_{SN} = \frac{a_N - 3\,c_S + \mu^d\,\tau_N + \mu^c\,\tau_N - 3\,\mu^d\,\tau_S - 3\,t + 2\,c_N}{4},$$

$$r^{c_1}_{NN} = \frac{a_N - 2\,c_N + \mu^d\,\tau_N - 3\,\mu^c\,\tau_N + \mu^d\,\tau_S + t + c_S}{4},$$

$$r^{d_1}_{NN} = \frac{a_N - 2\,c_N + \mu^c\,\tau_N - 3\,\mu^d\,\tau_N + \mu^d\,\tau_S + t + c_S}{4},$$

$$r^{d_1}_{SS} = \frac{a_S - 3\,c_S + \mu^d\,\tau_N + \mu^c\,\tau_N - 3\,\mu^d\,\tau_S + 2\,t + 2\,c_N}{4},$$

$$r^{d_1}_{NS} = \frac{a_S - 2\,c_N + \mu^c\,\tau_N - 3\,\mu^d\,\tau_N + \mu^d\,\tau_S - 2\,t + c_S}{4},$$

$$r^{c_1}_{NS} = \frac{a_S - 2\,c_N + \mu^d\,\tau_N - 3\,\mu^c\,\tau_N + \mu^d\,\tau_S - 2\,t + c_S}{4}.$$

On each market, the northern clean firm produces more than the northern dirty firm. A dirty firm always produces more on its domestic market than the dirty firm exporting on this market. Finally, depending on the transportation cost, taxes, and production costs, the clean firm may produce on each market more or less than the dirty southern firm. Indeed, the clean firm uses a more efficient technology but faces a higher tax and a higher production cost parameter c_N. Moreover, firms have an advantage on their domestic market since they do not pay the transportation cost when they supply their local market.

The equilibrium prices are then deduced and are as follows:

$$p_N^1 = \frac{\mu^d \tau_N + \mu^c \tau_N + \mu^d \tau_S + t + 2\, c_N + c_S + a_N}{4},$$
$$p_S^1 = \frac{\mu^d \tau_N + \mu^c \tau_N + \mu^d \tau_S + 2\, t + 2\, c_N + c_S + a_S}{4}.$$

It should be noted that a reduction in emissions intensity for both clean and dirty firms leads to lower product prices. In addition, a tightening of environmental policy in one of the two countries leads to higher product prices in both markets. Lower transport costs lead to lower product prices in each market An increase in a firm's production cost leads to higher prices in both markets. An increase in the market size of a country leads to an increase in the price of products sold in that country.

We also determine the emissions generated by the production, which are denoted by E_1^p and are equal to:

$$E_1^p = \frac{2\left(2\,\mu^d - \mu^c\right)\left(\mu^c \tau_N - \mu^d\, (\tau_N + \tau_S) - c_S\right) - 4\,\mu^c\, (\mu^c \tau_N + c_N) + \left(2\,\mu^d + \mu^c\right)(a_N + a_S - t)}{4}.$$

An increase in the market size of a country leads to an increase in emissions generated by production. An increase in production costs leads to a decrease in emissions generated by production. Note that emissions are not monotonic with emission intensities.

Similarly, we determine the emissions from the transport of goods which are denoted by E_1^t and equal to:

$$E_1^t = \gamma \frac{a_N + 2\, a_S - \mu^d \tau_N - \mu^c \tau_N - \mu^d \tau_S - 7\, t - 2c_N - c_S}{4}.$$

Transport-related emissions increase with market size and decrease with transport costs, production costs, emission taxes and emission intensities.

Case 2. North: one clean firm - South: two dirty firms. The northern firm uses the clean technology, while the two southern firms own the dirty technology. The three firms sell in the North and in the South. The superscript 2 refers to this case and the calculations are detailed in Appendix A.1. We show that the clean firm may produce more or less than the dirty southern firms. Indeed, the clean firm uses a more efficient technology but faces higher tax and production costs. Moreover, if the southern firms produce individually more than the northern firm in the northern market, then they produce also more on the southern market.

The equilibrium prices in this case are equal to:

$$p_N^2 = \frac{\mu^c\,\tau_N + 2\,\mu^d\,\tau_S + 2\,t + c_N + 2\,c_S + a_N}{4},$$
$$p_S^2 = \frac{\mu^c\,\tau_N + 2\,\mu^d\,\tau_S + t + c_N + 2\,c_S + a_S}{4}.$$

The emissions generated by the production, which are denoted by E_2^p, are equal to:

$$E_2^p = \frac{2\,(2\,\mu^d - 3\,\mu^c)\,(\mu^c\,\tau_N + c_N) - 4\,(2\,\mu^d - \mu^c)\,(\mu^d\,\tau_S + c_S) - (2\,\mu^d + \mu^c)\,(t - a_N - a_S)}{4}$$

The emissions from the transport of goods, which are denoted by E_2^t, are equal to:

$$E_2^t = \gamma\frac{2\,a_N + a_S - \mu^c\,\tau_N - 2\mu^d\,\tau_S - 7\,t - c_N - 2\,c_S}{4}.$$

Case 3. North: one dirty firm - South: one dirty and one clean firm. The northern firm uses the dirty technology, while in the South the two technologies coexist. The superscript 3 refers to this case and the calculations are detailed in Appendix A.2. On each market, the southern clean firm produces more than the southern dirty firm. Each southern firm produces more than the northern dirty firm on the southern market. The northern dirty firm may produce more or less than the southern firms in the northern market since it does not pay for the transportation cost.

The equilibrium prices are:

$$p_N^3 = \frac{\mu^d\,\tau_N + \mu^d\,\tau_S + \mu^c\,\tau_S + 2\,t + c_N + 2\,c_S + a_N}{4},$$
$$p_S^3 = \frac{\mu^d\,\tau_N + \mu^d\,\tau_S + \mu^c\,\tau_S + t + c_N + 2\,c_S + a_S}{4}.$$

The emissions generated by the production, which are denoted by E_3^p, are equal to:

$$E_3^p = \frac{2\,(\mu^c - 2\,\mu^d)\,\mu^d\,\tau_N - 2\,(2\,{\mu^d}^2 - 3\,\mu^c\,\Delta_\mu)\,\tau_S + (2\,\mu^d + \mu^c)\,(a_N + a_S - t - 2\,c_N)}{4} + \Delta_c\,\mu^c.$$

The emissions from the transport of goods, which are denoted by E_3^t, are equal to:

$$E_3^t = \gamma\frac{2\,a_N + a_S - \mu^d\,\tau_N - \mu^d\,\tau_S - \mu^c\,\tau_S - 7\,t - c_N - 2\,c_S}{4}.$$

Case 4. North: no firm - South: two dirty firms and one clean firm. The three firms produce in the South. One firm uses the clean technology, while the two others own the dirty technology. The superscript 4 refers to this case and the calculations are detailed in Appendix A.3. The marginal cost of producing and selling in the South is $c_S + \tau_S\, \mu^c$ for the clean firm and $c_S + \tau_S\, \mu^d$ for the dirty one. The two dirty firms produce the same, while the clean firm produces more since its marginal cost is lower. The productions obviously do not depend on the northern environmental tax and cost parameter.
The equilibrium prices are:

$$p_N^4 = \frac{2\,\mu^d\,\tau_S + \mu^c\,\tau_S + 3\,t + 3\,c_S + a_N}{4},$$
$$p_S^4 = \frac{2\,\mu^d\,\tau_S + \mu^c\,\tau_S + 3\,c_S + a_S}{4}.$$

The emissions generated by the production, which are denoted by E_4^p, are equal to:

$$E_4^p = \frac{\left(2\,\mu^d + \mu^c\right)\,(a_N + a_S - t - 2\,c_S) - 2\left(4\,\mu^d\,\Delta_\mu + 3\,\mu^{c2}\right)\,\tau_S}{4}.$$

The emissions from the transport of goods, which are denoted by E_4^t, are equal to:

$$E_4^t = \gamma\frac{3\,a_N - 2\,\mu^d\,\tau_S - \mu^c\,\tau_S - 3\,t - 3\,c_S}{4}.$$

2.3 The location decisions

Once we have described the four possible market structures, let us introduce the location decisions. We assume that two mobile firms decide simultaneously whether they change their location. The timing of the game is as follows:

- Stage 1: each mobile firm chooses its location.
- Stage 2: each firm chooses its production level given its location.

Before going into detail, we would like to clarify our approach. The aim of this paper is to study the effects of changes in location as a function of the production technology. Put another way, what interests us is to compare the four cases described above. It should also be noted that each of these cases can be explained by different firm movements. In other words, the equilibrium conditions depend on the firms' initial location. Indeed, if a mobile firm is located in the North, it can stay in the North or relocate to the South and bear the offshoring cost C^O. On the opposite, if a mobile firm is located in the South, it can stay in the South or relocate to the North and bear the reshoring cost C^R. The four cases, that we have studied previously, can be the baseline. First, we will study the decisions by considering that Case 1 is the baseline. In the appendix B.2, B.3, and B.4, we study the other three games by considering the other cases as the baseline.

We solve this game using backwards induction: each firm chooses its location given that in the second stage firms will compete in quantity. Assuming that initially the two mobile firms are located in the North, Figure 1 represents the extensive form of the game. Table 1 represents the normal form of the game.

Firms play simultaneously. The decision to relocate depends on the expected gains, the cost of relocation and the decision of the other mobile firm. From the extensive and the normal form, we determine the conditions under which each case is an equilibrium. These latter are presented in Appendix B.1. These conditions will allow us to analyse later in the paper how the regulator can use them to implement the market structure that seems most favourable to him/her. Whether one or both firms relocate or stay in the North depends on the cost of offshoring. Note moreover that depending on the value of the offshoring cost and the parameters, there may be multiple equilibria. To illustrate this, we have two numerical examples.

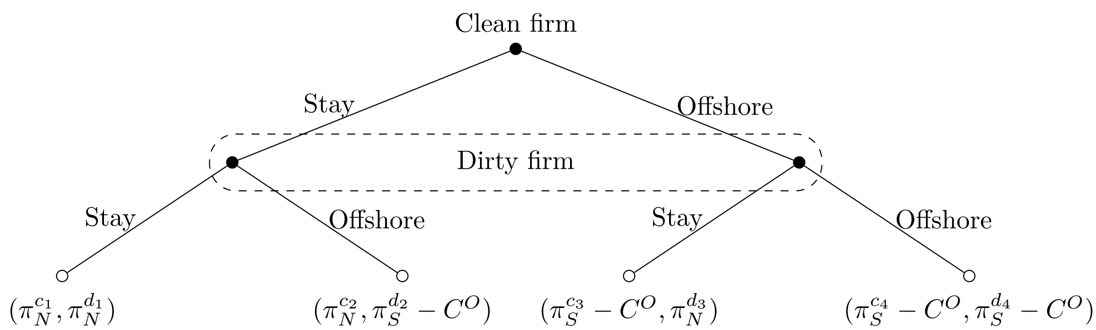

Figure 1: The extensive form of the game when initially the two mobile firms are located in the North.

		Dirty firm	
		Stay	Offshore
Clean firm	Stay	$(\pi_N^{c_1}, \pi_N^{d_1})$	$(\pi_N^{c_2}, \pi_S^{d_2} - C^O)$
	Offshore	$(\pi_S^{c_3} - C^O, \pi_N^{d_3})$	$(\pi_S^{c_4} - C^O, \pi_S^{d_4} - C^O)$

Table 1: The normal form of the game when initially the two mobile firms are located in the North.

As we can observe on Figures 2 and 3, in both cases, if the cost of relocation is low, both firms locate in the South. Offshoring is profitable for both firms. If it is very high, both firms remain in the North since relocation is not profitable. When the cost is medium, the two equilibria are possible (the dirty firm relocates while the clean firm remains, and the clean firm relocates while the dirty firm remains). We observe two intermediate situations where only one firm relocates (in the first, for instance, it is the dirty one and in the second it is the clean one.

In the case where in equilibrium only one firm relocates, its type (clean or dirty) depends on the comparison between $\pi_S^{c_3} - \pi_N^{c_1} - C^O$ and $\pi_S^{d_2} - \pi_N^{d_1} - C^O$. We show that $\pi_S^{c_3} - \pi_N^{c_1} - C^O$ may be higher or lower than $\pi_S^{d_2} - \pi_N^{d_1} - C^O$. Clean firms produce more after offshoring since they benefit from the lower production cost. The presence of a lower tax in the South induces two opposite effects. On the one hand, the low tax attracts clean firms since they produce more, but it is also appealing for dirty firms since they use a more polluting technology. By studying the previous equation, we demonstrate that $\pi_S^{c_3} - \pi_N^{c_1} - C^O > \pi_S^{d_2} - \pi_N^{d_1} - C^O$ when the transportation cost t and the production costs gap Δ_c are great, and when the market sizes are low.

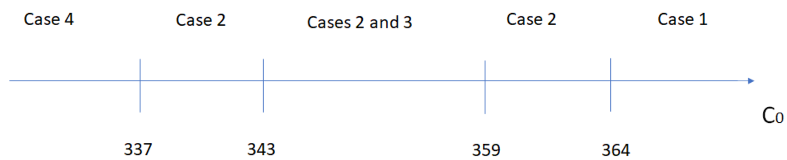

Figure 2: Cases which emerge at equilibrium according to the cost of reshoring for $a_S = a_N = 100$, $c_N = 10$, $c_S = 5$, $\mu^d = 1.5$, $\mu^c = 1$, $t = 1$, $\tau_S = 0.1$ and $\tau_N = 0.3$.

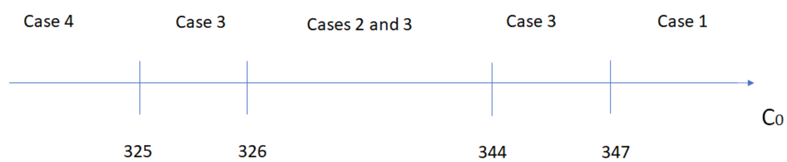

Figure 3: Cases which emerge at equilibrium according to the cost of reshoring for $a_S = a_N = 100$, $c_N = 10$, $c_S = 5$, $\mu^d = 1.5$, $\mu^c = 1$, $t = 1$, $\tau_S = 0.28$ and $\tau_N = 0.3$.

3 Comparing scenarios: the effects of offshoring

The purpose of this section is to compare the different scenarios. We focus on the case of offshoring, and therefore we assume that the two mobile firms are initially located in the North. In the next section we will discuss the reshoring case. We analyze the effects of offshoring on the four components of welfare, which are the environmental damage, the consumer surplus, the profits and the regulator's revenue.

The following proposition compares the effects of offshoring on the global emissions.

Proposition 1 *The effect of offshoring on global emissions depends on the type of relocated firm:*

- *If the southern market size is sufficiently great as compared to the northern market size, the offshoring of a dirty firm decreases emissions. Otherwise, the offshoring of a dirty firm increases emissions.*

- *If the southern market size is sufficiently great as compared to the northern market size and if the emission intensity of the clean technology is sufficiently lower than the emission intensity of the dirty technology, the offshoring of a clean firm decreases emissions. Otherwise, the offshoring of a clean firm increases emissions.*

- *Emissions are higher when the dirty firm relocates than when the clean firm relocates to the South.*

proof 1 *The proof, Appendix C.*

Offshoring affects both the emissions generated by production and those induced by the transport. The comparison between the effects on transport-related and production-related emissions depends of course on the level of emissions intensity of transport γ.

Offshoring affects the production-related emissions through a change in the production of the relocated firm (direct effect), and also through the response of the other firms (indirect effect). By offshoring, the firm benefits from a low emissions tax and a low production cost, hence, it increases its production and emissions. On the opposite, the other firms decrease their production and emissions since they now face a more competitive firm.

Production-related emissions always increase with the offshoring of a dirty firm. Indeed, the direct effect dominates the indirect one. In other words, the increase in emissions from the dirty relocated firm outweighs the decrease in emissions from its competitors. On the opposite, production-related emissions only increase with the offshoring of a clean firm if $\mu^c > \frac{2}{3}\mu^d$, hence the indirect effect may dominate the direct one. Indeed, since dirty firms react to the offshoring of a clean one by decreasing their production, offshoring reduces production-related emissions when μ^d is relatively large. On the opposite, since the relocated clean firm increases its production, offshoring increases production-related emissions when μ^c is relatively great. Hence, the offshoring of a clean firm increases the production-related emissions when the technological gap is relatively low.

Production-related emissions are higher when the dirty firm relocates than when the clean firm relocates. Indeed, a dirty relocated firm increases more its production than a clean relocated firm since a dirty firm benefits more from the low emissions tax. In addition, since it uses a dirtier technology, the increase in production-related emissions from the relocated firm is higher when a dirty firm relocates. Moreover, the southern firm decreases more its production (and emissions) when a dirty firm relocates than when a clean firm relocates.

Let us now focus on transport-related emissions. These depend on the total volume of trade between North and South. If the market size in the South is large enough, the relocation of a firm (dirty or clean) will reduce transport-related emissions because the relocation reduces the total volume of trade between North and South. Moreover, the relocation of a clean firm to the South will increase more substantially exports and the transport-related emissions than the relocation of a dirty firm.

To conclude the offshoring of a clean firm is better for the environment than the offshoring of a dirty firm.

Let us focus on the northern consumer surplus, which is equal to $\frac{1}{2}(a_N - p_N)^2$. The following proposition compares the effects of offshoring on the northern consumer surplus.

Proposition 2 *The effect of offshoring on the northern consumer surplus depends on the type of relocated firm:*

- *the northern consumer surplus increases with offshoring if and only if the transportation cost is low,*

- *the northern consumer surplus is higher when a dirty firm relocates than when a clean firm relocates.*

proof 2 *The proof, Appendix D.*

If the transportation cost is low, offshoring induces a decrease in the northern price. Indeed, the relocated firm is more efficient as it benefits from a lower production cost, a lower emissions tax, and only pays for a low transportation cost to export the good. Therefore, the relocated firm produces more than before relocating and the northern price will be lower. When the transportation cost is great, efficiency gains do not offset transportation cost and sales in the North will be lower than before relocation. Moreover, the northern price is lower when a dirty firm relocates than when a clean one relocates. Indeed, the efficiency gains are higher when the relocated firm is dirty than when it is clean.

Offshoring clearly decreases the price in the South. Relocated firms benefit from low production costs, a low tax and save on transportation costs when they supply the market locally. Hence, the lowest southern price occurs when both firms relocate. Moreover, the price is lower when a dirty firm relocates than when a clean firm relocates. Hence, the southern consumers benefit from having more firms producing in the South, and they benefit even more if the firm is dirty.

Let us focus on the northern tax revenue, which is equal to the northern emissions times the emission tax in the North. Let us recall that we assume that only production related emissions are taxed. The following proposition determines the effects of offshoring on the northern tax revenue.

Proposition 3 *The effect of offshoring on the northern tax revenue depends on the type of relocated firm:*

- *the offshoring of either a dirty or a clean firm decreases the northern tax revenue,*

- *the offshoring of a clean firm may induce a lower or a higher decrease in tax revenue than the offshoring of a dirty firm.*

proof 3 *The proof, Appendix E.*

The offshoring of either a dirty or a clean firm decreases the northern tax revenue since the total northern production-related emissions decrease with offshoring. Nevertheless, the tax revenue may be either higher or lower in the dirty firm offshoring case than in the clean firm offshoring case. Indeed, a clean firm produces more (high tax revenue) but it pollutes less by units produced (low tax revenue). The tax revenue tends to be greater when a dirty firm relocates than when a clean firm relocates if the transportation cost, the production cost gap, and the tax gap are great, and when the market sizes are low. In other words, the government is able to capture more tax revenue from clean firms when southern firms are highly competitive.

The following proposition determines the effects of offshoring on the sum of northern profits.

Proposition 4 *The effect of offshoring on the sum of northern profits depends on the type of relocated firm:*

- *offshoring always decreases northern profits if the transportation cost is relatively low,*
- *offshoring may increase northern profits if the transportation cost is relatively great and if the profits on the northern market are sufficiently large,*
- *the northern profits are higher when the dirty firm relocates (and the clean firm stays) than when the clean firm relocates (and the dirty firm stays).*

proof 4 *The proof, Appendix F.*

The effect of offshoring on northern profits is threefold. (i) The profits of the relocated firm disappear. (ii) The profits of the remaining firm on the southern market decrease since the relocated firm is more productive on the southern market. (iii) Finally, the profits of the remaining firm on the northern market increase if the transportation cost is high enough and decrease otherwise. Hence, if the transportation cost is low, offshoring always decreases northern profits. Northern profits can only increase with offshoring if the market size in the North is larger than the one in the South and if transportation costs are great (necessary but not sufficient condition). For a given location, the clean firm produces at a lower cost than a dirty firm since it uses a cleaner technology. As a result, for a given location, clean firms make higher profits than dirty firms. Hence, the northern profits are higher when a dirty firm relocates and a clean firm remains in the North than when a clean firm relocates, and a dirty firm remains in the North.

4 Discussion and policy implications

Let us study first the counterpart of the offshoring, the reshoring, and discuss the robustness and the policy implications of our results.

First of all, the effects of reshoring are opposite to those of offshoring. Reshoring only decreases the northern price if the transportation cost is relatively high, that is, if producing in the North is less expensive than exporting. Then, reshoring always increases the tax revenue, however, this increase can be higher or lower when a dirty firm relocates than when a clean firm relocates. As with offshoring, there are two opposite effects: a dirty firm produces less but pollutes more per unit produced. If the southern market size is sufficiently great as compared to the northern market size, the reshoring of a dirty firm increases emissions. Otherwise, the reshoring of a dirty firm decreases emissions. If the southern market size is sufficiently great as compared to the northern market size and if the emission intensity of the clean technology is sufficiently lower than the emission intensity of the dirty technology, the reshoring of a clean firm increases emissions. Otherwise, the reshoring of a clean firm decreases emissions. Emissions are lower when the dirty firm relocates than when the clean firm relocates to the North. Finally, if there is no industry in the North, reshoring necessarily increases the northern profits, and the profits are higher if a clean firm relocates to the North. Nevertheless, if there is already a firm located in the North (the incumbent), the reshoring of a firm, can increase or decrease the northern profits. Indeed, reshoring can decrease the profits of the incumbent firm on the northern market if the transportation cost is relatively high.

Let us now discuss the robustness of our results. Until now we have not taken into account the fact that technology property rights are less protected in the South than in the North. This makes it easier to copy and imitate a technology in the South than in the North. Therefore, offshoring can lead to technological spillovers, and the offshoring of a clean firm can induce an improvement in the technology of the southern dirty firm. The spillovers strengthen the competition in both markets. As a result, with offshoring, the northern consumers will be better off, the profits of the remaining firm in the North will be lower, and the North will lose even more tax revenue. Nevertheless, the effect of spillovers on the environment is ambiguous. Indeed, on the one hand, spillovers decrease the production and the emissions of both the relocated firm and the northern dirty firm, and on the other hand, increase the production of the former-dirty firm. The spillovers in our setting will have no effect on reshoring.

In this paper, we have assumed that the technology used by the firm is only defined by the emission intensity factor μ and that the production cost is country specific. However, we could relax this assumption by assuming that the firm's technology is defined by a couple emission intensity and production cost. If we assume that a clean firm produces at a higher cost, then northern firms will have less incentives to offshore, consumers will benefit less from relocation, and relocation will less reinforce competition.

So far, we have considered that a firm, which relocates, closes its production site in the North and opens a new site in the South. However, multinational companies from the North can open subsidiaries in the South. Assuming as in Motta and Thisse (1994) that the home firm and its subsidiary only supply the good locally, if the subsidiary is created from scratch, our results are qualitatively unchanged and on each market there is always the same number of firms. However, if the subsidiary is created by acquiring a dirty firm in the South, the new market structure will be more concentrated in the South and firms can exercise a higher market-power.

The results, such as the relocation of a dirty firm as compared to the relocation of a clean firm is worse for the environment, better for northern consumers, and better for the domestic profits, are also robust with the presence of several dirty and several clean firms.

We can now turn our attention to the policy implications of our paper. It is important to note that a government is characterised by its environmental preferences (in other words, its valuation of environmental damage), the weight it will give to consumers and companies in its decisions, and its financial constraints (need to raise tax revenues to finance public policies or public debt). Our model shows that depending on its preferences, a government is able to rank the different market structures and it may be willing to prevent relocations. However, countries are particularly heavily indebted and they can be forced, instead of preventing two firms from relocating, to prevent only one. In the same way, they can be forced to select which type of firms to encourage to reshore. This raises a question. Should the clean or the dirty firm be preferred? Our model shows that if the marginal environmental damage is particularly significant, the regulator has an interest in preventing (encouraging) dirty firms from offshoring (reshoring). Moreover, when the technological gap is sufficiently low and the marginal environmental damage is sufficiently great, the regulator has incentives in preventing (encouraging) clean firms from offshoring (reshoring). Finally, if the government cares more about the economic activities than about consumers, it may be more willing to prevent (encourage) clean firms from offshoring (reshoring).

The government's choice of a particular market structure also depends on the costs to reach this given market structure. The costs are in fact the subsidies given to a firm to affect its location decision. Hence, the means to implement the chosen market structure is related to the equilibrium conditions studied in Section B.1 to B.4. One possibility is to impact the relocation costs of the dirty firm and the clean firm differently in order to obtain the desired market structure at equilibrium. This may involve introducing differentiated subsidies. Treating firms differently is, however, a sensitive issue from both an acceptability and a legal point of view. From a legal point of view, it is imperative to be able to demonstrate that such a solution is proportionate, satisfies the general interest and does not create barriers to market access for firms from other European countries.

Finally, this paper also highlights that offshoring can reduce transportation-related emissions. Indeed, when the market size in the South is large enough, the relocation of a firm will reduce transport-related emissions because the relocation reduces the total volume of trade between North and South. Transportation-related emissions depend on the type of transportation mode which in turn depends on the type of traded goods. If we focus on trade between China and the EU, EU's main imports from China are industrial and consumer goods, machinery and equipment, and clothing, while EU's main exports to China are machinery and equipment, motor vehicles, aircraft, and chemicals. Despite, this variety of traded goods, according to the United Nations Economic Commission for Europe 62% of China-EU trade is done using maritime transport, 23% using flights, and only 7% using road. It should be noted that maritime transport generates greenhouse gas emissions but also sulphur dioxide (SO2), nitrogen oxides (NOx) and fine particles which is consistent with our assumption that transport creates emissions with global effects.

5 Conclusion

The results of this paper can be interpreted from both a positive and a normative point of view. First, on the positive side, this paper shows that the effects of relocation depend on the environmental quality of the technology used. Relocation of clean and dirty firms does not have the same distributive effects. Hence, it is demonstrated that the offshoring (reshoring) of a dirty firm as compared to the offshoring (reshoring) of a clean firm is worse (better) for the environment, better (worse) for northern consumers, and better (worse) for the domestic profits. From a normative point of view, when the environmental damage is large enough, the regulator has an interest in preventing dirty firms from offshoring. Moreover, when the technological gap is sufficiently low and the marginal environmental damage is sufficiently great, the regulator has incentives in preventing clean firms from offshoring.

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Appendixes

A The productions and the prices at equilibrium

A.1 North: one clean firm - South: two dirty firms

The clean firm solves the following problem:

$$\max_{r^c_{NS}, r^c_{NN}} \pi^c_N = (p_S - c_N - \tau_N \mu^c - t)\, r^c_{NS} + (p_N - c_N - \tau_N \mu^c)\, r^c_{NN}. \tag{4}$$

Each dirty firm solves the following problem:

$$\max_{r^d_{SS_i}, r^d_{SN_i}} \pi^d_S = (p_S - c_S - \tau_S \mu^d)\, r^d_{SS_i} + (p_N - c_S - \tau_S \mu^d - t)\, r^d_{SN_i}. \tag{5}$$

The production levels are:

$$\begin{aligned}
r^{d_2}_{SN} &= \frac{a_N - 2\,c_S + \mu^c\,\tau_N - 2\,\mu^d\,\tau_S - 2\,t + c_N}{4},\\
r^{c_2}_{NN} &= \frac{a_N - 3\,c_N + 2\,\mu^d\,\tau_S - 3\,\mu^c\,\tau_N + 2\,t + 2\,c_S}{4},\\
r^{d_2}_{SS} &= \frac{a_S - 2\,c_S + \mu^c\,\tau_N - 2\,\mu^d\,\tau_S + t + c_N}{4},\\
r^{c_2}_{NS} &= \frac{a_S - 3\,c_N + 2\,\mu^d\,\tau_S - 3\,\mu^c\,\tau_N - 3\,t + 2\,c_S}{4}.
\end{aligned}$$

A.2 North: one dirty firm - South: one dirty and one clean firm

The dirty firm in the North solves the following problem:

$$\max_{r^d_{NS}, r^d_{NN}} \pi^d_N = (p_S - c_N - \tau_N \mu^d - t)\, r^d_{NS} + (p_N - c_N - \tau_N \mu^d)\, r^d_{NN}. \tag{6}$$

The clean firm in the South solves the following problem:

$$\max_{r^c_{SS}, r^c_{SN}} \pi^c_S = (p_S - c_S - \tau_S \mu^c)\, r^c_{SS} + (p_N - c_S - \tau_S \mu^c - t)\, r^c_{SN}. \tag{7}$$

The dirty firm in the South solves the following problem:

$$\max_{r^d_{SS}, r^d_{SN}} \pi^d_S = (p_S - c_S - \tau_S \mu^d)\, r^d_{SS} + (p_N - c_S - \tau_S \mu^d - t)\, r^d_{SN}. \tag{8}$$

The production levels are:

$$r_{SS}^{c_3} = \frac{a_S - 2\,c_S + \mu^d\,\tau_N + \mu^d\,\tau_S - 3\,\mu^c\,\tau_S + t + c_N}{4},$$
$$r_{SS}^{d_3} = \frac{a_S - 2\,c_S + \mu^d\,\tau_N - 3\,\mu^d\,\tau_S + \mu^c\,\tau_S + t + c_N}{4},$$
$$r_{NS}^{d_3} = \frac{a_S - 3\,c_N + \mu^d\,\tau_S - 3\,\mu^d\,\tau_N + \mu^c\,\tau_S - 3\,t + 2\,c_S}{4},$$
$$r_{SN}^{c_3} = \frac{a_N - 2\,c_S + \mu^d\,\tau_N + \mu^d\,\tau_S - 3\,\mu^c\,\tau_S - 2\,t + c_N}{4},$$
$$r_{SN}^{d_3} = \frac{a_N - 2\,c_S + \mu^d\,\tau_N - 3\,\mu^d\,\tau_S + \mu^c\,\tau_S - 2\,t + c_N}{4},$$
$$r_{NN}^{d_3} = \frac{a_N - 3\,c_N + \mu^d\,\tau_S - 3\,\mu^d\,\tau_N + \mu^c\,\tau_S + 2\,t + 2\,c_S}{4}.$$

A.3 North: no firm - South: two dirty firms and one clean firm

The clean firm solves the following problem:

$$\max_{r_{SS}^c, r_{SN}^c} \pi_S^c = (p_S - c_S - \tau_S\,\mu^c)\,r_{SS}^c + (p_N - c_S - \tau_S\,\mu^c - t)\,r_{SN}^c. \tag{9}$$

The two dirty firms solve the following problem:

$$\max_{r_{SS_i}^d, r_{SN_i}^d} \pi_{S_i}^d = (p_S - c_S - \tau_S\,\mu^d)\,r_{SS_i}^d + (p_N - c_S - \tau_S\,\mu^d - t)\,r_{SN_i}^d. \tag{10}$$

The production levels are:

$$r_{SN}^{c_4} = \frac{a_N - c_S + 2\,\mu^d\,\tau_S - 3\,\mu^c\,\tau_S - t}{4},$$
$$r_{SN}^{d_4} = \frac{a_N - c_S + \mu^c\,\tau_S - 2\,\mu^d\,\tau_S - t}{4},$$
$$r_{SS}^{c_4} = \frac{a_S - c_S + 2\,\mu^d\,\tau_S - 3\,\mu^c\,\tau_S}{4},$$
$$r_{SS}^{d_4} = \frac{a_S - c_S + \mu^c\,\tau_S - 2\,\mu^d\,\tau_S}{4}.$$

B Equilibrium

B.1 Benchmark: case 1

- Case 1: $(\pi_N^{c_1}, \pi_N^{d_1})$ is an equilibrium if:

$\pi_N^{c_1} > \pi_S^{c_3} - C^O$ and $\pi_N^{d_1} > \pi_S^{d_2} - C^O$. It is unique if $(\pi_S^{c_4} - C^O, \pi_S^{d_4} - C^O)$ is not an equilibrium that is if $\pi_S^{c_4} - C^O > \pi_N^{c_2}$, then $\pi_S^{d_4} - C^O < \pi_N^{d_3}$, or if $\pi_S^{d_4} - C^O > \pi_N^{d_3}$, then $\pi_S^{c_4} - C^O < \pi_N^{c_2}$.

- Case 2: $(\pi_N^{c_2}, \pi_S^{d_2} - C^O)$ is an equilibrium if:

$\pi_N^{c_2} > \pi_S^{c_4} - C^O$ and $\pi_S^{d_2} - C^O > \pi_N^{d_1}$. It is unique if $(\pi_S^{c_3} - C^O, \pi_N^{d_3})$ is not an equilibrium that is if $\pi_S^{c_3} - C^O > \pi_N^{c_1}$, then $\pi_N^{d_3} < \pi_S^{d_4} - C^O$, or if $\pi_N^{d_3} > \pi_S^{d_4} - C^O$, then $\pi_S^{c_3} - C^O < \pi_N^{c_1}$.

- Case 3: $(\pi_S^{c_3} - C^O, \pi_N^{d_3})$ is an equilibrium if:

$\pi_S^{c_3} - C^O > \pi_N^{c_1}$ and $\pi_N^{d_3} > \pi_S^{d_4} - C^O$. It is unique if $(\pi_N^{c_2}, \pi_S^{d_2} - C^O)$ is not an equilibrium that is if $\pi_N^{c_2} > \pi_S^{c_4} - C^O$, then $\pi_S^{d_2} - C^O < \pi_N^{d_1}$, or if $\pi_S^{d_2} - C^O > \pi_N^{d_1}$, then $\pi_N^{c_2} < \pi_S^{c_4} - C^O$.

- Case 4: $(\pi_S^{c_4} - C^O, \pi_S^{d_4} - C^O)$ is an equilibrium if:

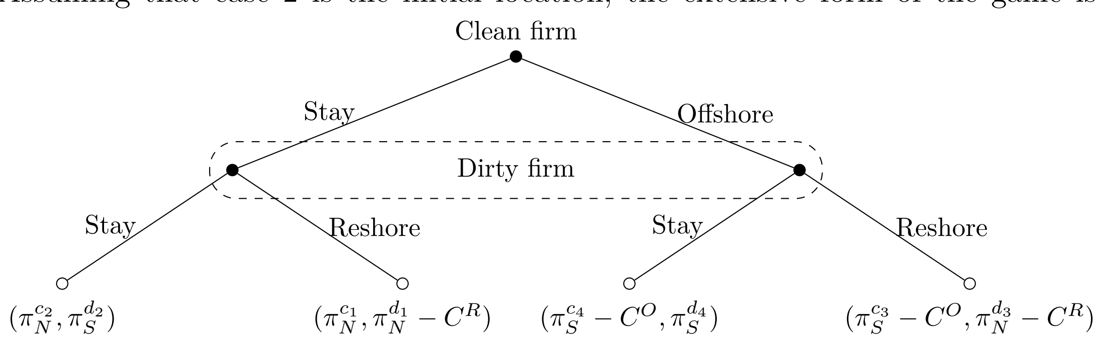
$\pi_S^{c_4} - C^O > \pi_N^{c_2}$ and $\pi_S^{d_4} - C^O > \pi_N^{d_3}$. It is unique if $(\pi_N^{c_1}, \pi_N^{d_1})$ is not an equilibrium that is if $\pi_N^{c_1} > \pi_S^{c_3} - C^O$, then $\pi_N^{d_1} < \pi_S^{d_2} - C^O$, or if $\pi_N^{d_1} > \pi_S^{d_2} - C^O$, then $\pi_N^{c_1} < \pi_S^{c_3} - C^O$.

Simulation 1: $a_S = a_N = 100$; $c_N = 10$; $c_S = 5$; $\mu^d = 1.5$; $\mu^c = 1$; $t = 1$; $\tau_S = 0.1$ and $\tau_N = 0.3$.
$\pi_N^{c_1} = 886$; $\pi_N^{d_1} = 874$; $\pi_S^{d_1} = 1374$
$\pi_N^{c_2} = 779$; $\pi_S^{d_2} = 1238$
$\pi_N^{d_3} = 769$; $\pi_S^{d_3} = 1240$; $\pi_S^{c_3} = 1245$
$\pi_S^{d_4} = 1112$; $\pi_S^{c_4} = 1116$.

From simulation 1 to 2, we decrease the taxation gap:
Simulation 2: $a_S = a_N = 100$; $c_N = 10$; $c_S = 5$; $\mu^d = 1.5$; $\mu^c = 1$; $t = 1$; $\tau_S = 0.28$ and $\tau_N = 0.3$.
$\pi_N^{c_1} = 892$; $\pi_N^{d_1} = 880$; $\pi_S^{d_1} = 1353$
$\pi_N^{c_2} = 790$; $\pi_S^{d_2} = 1224$
$\pi_N^{d_3} = 778$; $\pi_S^{d_3} = 1225$; $\pi_S^{c_3} = 1239$
$\pi_S^{d_4} = 1103$; $\pi_S^{c_4} = 1116$.

B.2 Benchmark: case 2

Assuming that case 2 is the initial location, the extensive form of the game is as follows:



The normal form of the game is as follows:

		Dirty firm: Stay	Dirty firm: Reshore
Clean firm	Stay	$(\pi_N^{c_2}, \pi_S^{d_2})$	$(\pi_N^{c_1}, \pi_N^{d_1} - C^R)$
	Offshore	$(\pi_S^{c_4} - C^O, \pi_S^{d_4})$	$(\pi_S^{c_3} - C^O, \pi_N^{d_3} - C^R)$

- Case 1: $(\pi_N^{c_1}, \pi_N^{d_1} - C^R)$ is an equilibrium if:

$\pi_N^{c_1} > \pi_S^{c_3} - C^O$ and $\pi_N^{d_1} - C^R > \pi_S^{d_2}$. It is unique if $(\pi_S^{c_4} - C^O, \pi_S^{d_4})$ is not an equilibrium, that is if $\pi_S^{c_4} - C^O > \pi_N^{c_2}$, then $\pi_S^{d_4} < \pi_N^{d_3} - C^R$, or if $\pi_S^{d_4} > \pi_N^{d_3} - C^R$, then $\pi_S^{c_4} - C^O < \pi_N^{c_2}$.

- Case 2: $(\pi_N^{c_2}, \pi_S^{d_2})$ is an equilibrium if:

$\pi_N^{c_2} > \pi_S^{c_4} - C^O$ and $\pi_S^{d_2} > \pi_N^{d_1} - C^R$. It is unique if $(\pi_S^{c_3} - C^O, \pi_N^{d_3} - C^R)$ is not an equilibrium that is if $\pi_S^{c_3} - C^O > \pi_N^{c_1}$, then $\pi_N^{d_3} - C^R < \pi_S^{d_4}$, or if $\pi_N^{d_3} - C^R > \pi_S^{d_4}$, then $\pi_S^{c_3} - C^O < \pi_N^{c_1}$.

- Case 3: $(\pi_S^{c_3} - C^O, \pi_N^{d_3} - C^R)$ is an equilibrium if:

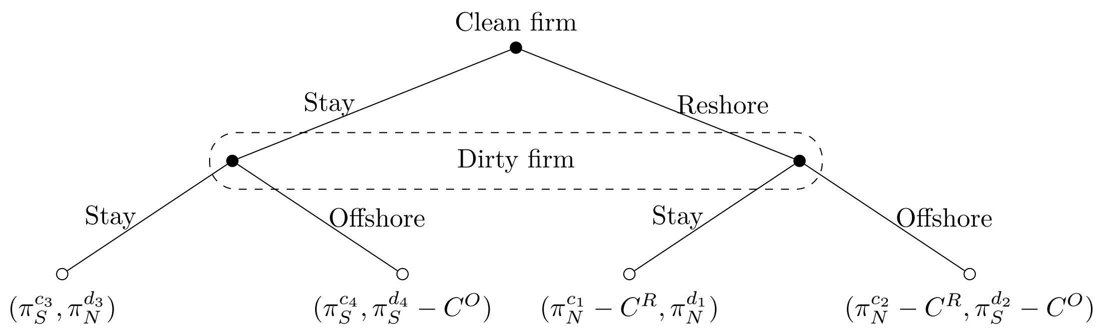
$\pi_S^{c_3} - C^O > \pi_N^{c_1}$ and $\pi_N^{d_3} - C^R > \pi_S^{d_4}$. It is unique if $(\pi_N^{c_2}, \pi_S^{d_2})$ is not an equilibrium that is if $\pi_N^{c_2} > \pi_S^{c_4} - C^O$, then $\pi_S^{d_2} < \pi_N^{d_1} - C^R$, or if $\pi_S^{d_2} > \pi_N^{d_1} - C^R$, then $\pi_N^{c_2} < \pi_S^{c_4} - C^O$.

- Case 4: $(\pi_S^{c_4} - C^O, \pi_S^{d_4})$ is an equilibrium if:

$\pi_S^{c_4} - C^O > \pi_N^{c_2}$ and $\pi_S^{d_4} > \pi_N^{d_3} - C^R$. It is unique if $(\pi_N^{c_1}, \pi_N^{d_1} - C^R)$ is not an equilibrium that is if $\pi_N^{c_1} > \pi_S^{c_3} - C^O$, then $\pi_N^{d_1} - C^R < \pi_S^{d_2}$, or if $\pi_N^{d_1} - C^R > \pi_S^{d_2}$, then $\pi_N^{c_1} < \pi_S^{c_3} - C^O$.

B.3 Benchmark: case 3

Assuming that case 3 is the initial location, the extensive form of the game is as follows:



The normal form of the game is as follows:

		Dirty firm	
		Stay	Offshore
Clean firm	Stay	$\left(\pi_S^{c_3}, \pi_N^{d_3}\right)$	$\left(\pi_S^{c_4}, \pi_S^{d_4} - C^O\right)$
	Reshore	$\left(\pi_N^{c_1} - C^R, \pi_N^{d_1}\right)$	$\left(\pi_N^{c_2} - C^R, \pi_S^{d_2} - C^O\right)$

- Case 1: $\left(\pi_N^{c_1} - C^R, \pi_N^{d_1}\right)$ is an equilibrium if:

$\pi_N^{c_1} - C^R > \pi_S^{c_3}$ and $\pi_N^{d_1} > \pi_S^{d_2} - C^O$. It is unique if $\left(\pi_S^{c_4}, \pi_S^{d_4} - C^O\right)$ is not an equilibrium, that is if $\pi_S^{c_4} > \pi_N^{c_2} - C^R$, then $\pi_S^{d_4} - C^O < \pi_N^{d_3}$, or if $\pi_S^{d_4} - C^O > \pi_N^{d_3}$, then $\pi_S^{c_4} < \pi_N^{c_2} - C^R$.

- Case 2: $\left(\pi_N^{c_2} - C^R, \pi_S^{d_2} - C^O\right)$ is an equilibrium if:

$\pi_N^{c_2} - C^R > \pi_S^{c_4}$ and $\pi_S^{d_2} - C^O > \pi_N^{d_1}$. It is unique if $\left(\pi_S^{c_3}, \pi_N^{d_3}\right)$ is not an equilibrium that is if $\pi_S^{c_3} > \pi_N^{c_1} - C^R$, then $\pi_N^{d_3} < \pi_S^{d_4} - C^O$, or if $\pi_N^{d_3} > \pi_S^{d_4} - C^O$, then $\pi_S^{c_3} < \pi_N^{c_1} - C^R$.

- Case 3: $\left(\pi_S^{c_3}, \pi_N^{d_3}\right)$ is an equilibrium if:

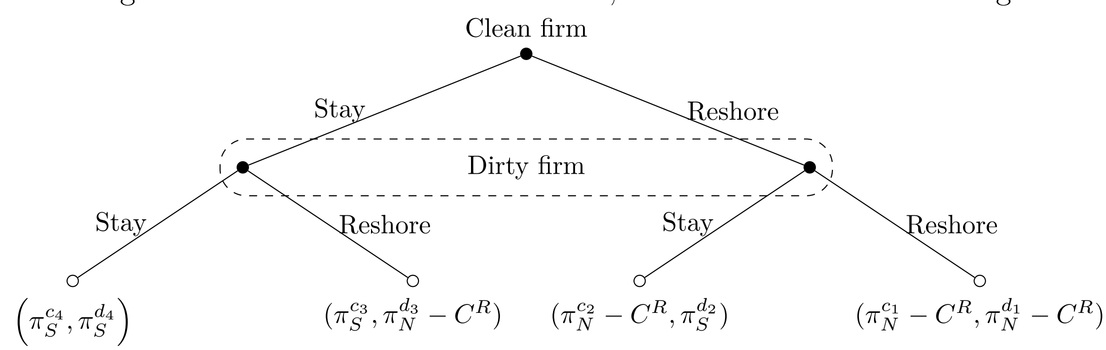
$\pi_S^{c_3} > \pi_N^{c_1} - C^R$ and $\pi_N^{d_3} > \pi_S^{d_4} - C^O$. It is unique if $(\pi_N^{c_2} - C^R, \pi_S^{d_2} - C^O)$ is not an equilibrium that is if $\pi_N^{c_2} - C^R > \pi_S^{c_4}$, then $\pi_S^{d_2} - C^O < \pi_N^{d_1}$, or if $\pi_S^{d_2} - C^O > \pi_N^{d_1}$, then $\pi_N^{c_2} - C^R < \pi_S^{c_4}$.

- Case 4: $\left(\pi_S^{c_4}, \pi_S^{d_4} - C^O\right)$ is an equilibrium if:

$\pi_S^{c_4} > \pi_N^{c_2} - C^R$ and $\pi_S^{d_4} - C^O > \pi_N^{d_3}$. It is unique if $\left(\pi_N^{c_1} - C^R, \pi_N^{d_1}\right)$ is not an equilibrium that is if $\pi_N^{c_1} - C^R > \pi_S^{c_3}$, then $\pi_N^{d_1} < \pi_S^{d_2} - C^O$, or if $\pi_N^{d_1} > \pi_S^{d_2} - C^O$, then $\pi_N^{c_1} - C^R < \pi_S^{c_3}$.

B.4 Benchmark: case 4

Assuming that case 4 is the initial location, the extensive form of the game is as follows:



The normal form of the game is as follows:

		Dirty firm: Stay	Dirty firm: Reshore
Clean firm	Stay	$\left(\pi_S^{c_4}, \pi_S^{d_4}\right)$	$(\pi_S^{c_3}, \pi_N^{d_3} - C^R)$
	Reshore	$\left(\pi_N^{c_2} - C^R, \pi_S^{d_2}\right)$	$\left(\pi_N^{c_1} - C^R, \pi_N^{d_1} - C^R\right)$

- Case 1: $(\pi_N^{c_1} - C^R, \pi_N^{d_1} - C^R)$ is an equilibrium if:

$\pi_N^{c_1} - C^R > \pi_S^{c_3}$ and $\pi_N^{d_1} - C^R > \pi_S^{d_2}$. It is unique if $\left(\pi_S^{c_4}, \pi_S^{d_4}\right)$ is not an equilibrium, that is if $\pi_S^{c_4} > \pi_N^{c_2} - C^R$, then $\pi_S^{d_4} < \pi_N^{d_3} - C^R$, or if $\pi_S^{d_4} > \pi_N^{d_3} - C^R$, then $\pi_S^{c_4} < \pi_N^{c_2} - C^R$.

- Case 2: $(\pi_N^{c_2} - C^R, \pi_S^{d_2})$ is an equilibrium if:

$\pi_N^{c_2} - C^R > \pi_S^{c_4}$ and $\pi_S^{d_2} > \pi_N^{d_1} - C^R$. It is unique if $(\pi_S^{c_3}, \pi_N^{d_3} - C^R)$ is not an equilibrium that is if $\pi_S^{c_3} > \pi_N^{c_1} - C^R$, then $\pi_N^{d_3} - C^R < \pi_S^{d_4}$, or if $\pi_N^{d_3} - C^R > \pi_S^{d_4}$, then $\pi_S^{c_3} < \pi_N^{c_1} - C^R$.

- Case 3: $(\pi_S^{c_3}, \pi_N^{d_3} - C^R)$ is an equilibrium if:

$\pi_S^{c_3} > \pi_N^{c_1} - C^R$ and $\pi_N^{d_3} - C^R > \pi_S^{d_4}$. It is unique if $(\pi_N^{c_2} - C^R, \pi_S^{d_2})$ is not an equilibrium that is if $\pi_N^{c_2} - C^R > \pi_S^{c_4}$, then $\pi_S^{d_2} < \pi_N^{d_1} - C^R$, or if $\pi_S^{d_2} > \pi_N^{d_1} - C^R$, then $\pi_N^{c_2} - C^R < \pi_S^{c_4}$.

- Case 4: $\left(\pi_S^{c_4}, \pi_S^{d_4}\right)$ is an equilibrium if:

$\pi_S^{c_4} > \pi_N^{c_2} - C^R$ and $\pi_S^{d_4} > \pi_N^{d_3} - C^R$. It is unique if $(\pi_N^{c_1} - C^R, \pi_N^{d_1} - C^R)$ is not an equilibrium that is if $\pi_N^{c_1} - C^R > \pi_S^{c_3}$, then $\pi_N^{d_1} - C^R < \pi_S^{d_2}$, or if $\pi_N^{d_1} - C^R > \pi_S^{d_2}$, then $\pi_N^{c_1} - C^R < \pi_S^{c_3}$.

C Proof of Proposition 1

To determine the effects of the offshoring of a dirty firm, we have to compare case 1 to case 2, and case 3 to case 4. Moreover, to study the effect of the offshoring of a clean firm, we have to compare case 1 to case 3, and case 2 to 4. We calculate the emissions generated by production for each of the four cases and compare them.

$$E_1^p - E_2^p = E_3^p - E_4^p = -\frac{\left(2\,\mu^d - \mu^c\right)\,\left(\mu^d\,\Delta_\tau + \Delta_c\right)}{2} < 0,$$
$$E_1^p - E_3^p = E_2^p - E_4^p = \frac{\left(2\,\mu^d - 3\,\mu^c\right)\,\left(\mu^c\,\Delta_\tau + \Delta_c\right)}{2},$$
$$E_1^p - E_4^p = -\frac{\left(3\,\mu^c\,\Delta_\mu - 2\,\mu^{d^2}\right)\,\Delta_\tau - 2\,\Delta_c\,\mu^c}{2} < 0,$$
$$E_2^p - E_3^p = \frac{\Delta_\mu\,\left(\left(2\,\mu^d + 3\,\mu^c\right)\,\Delta_\tau + 4\,\Delta_c\right)}{2} > 0.$$

$E_1^p - E_3^p > 0$ and $E_2^p - E_4^p > 0$ if and only if $2\,\mu^d - 3\,\mu^c > 0$.

We compare emissions generated by the transport according to the various cases:

$$E_1^t - E_2^t = \frac{a_S - a_N - \Delta_\tau\,\mu^d - \Delta_c}{4},$$
$$E_1^t - E_3^t = \frac{a_S - a_N - \Delta_\tau\,\mu^c - \Delta_c}{4},$$
$$E_1^t - E_4^t = \frac{2\,(a_S - a_N) - 4\,t - \Delta_\tau\,\left(\mu^d + \mu^c\right) - 2\Delta_c}{4},$$
$$E_2^t - E_3^t = \frac{\Delta_\tau\,\Delta_\mu}{4},$$
$$E_2^t - E_4^t = \frac{a_S - a_N - 4\,t - \Delta_\tau\,\mu^c - \Delta_c}{4},$$
$$E_3^t - E_4^t = \frac{a_S - a_N - 4\,t - \Delta_\tau\,\mu^d - \Delta_c}{4}.$$

D Proof of Proposition 2

Once again, to determine the effects of the offshoring of a dirty firm, we have to compare case 1 to case 2, and case 3 to case 4. Moreover, to study the effect of the offshoring of a clean firm, we have to compare case 1 to case 3, and case 2 to 4. We compare prices according to the various cases:

$$
\begin{aligned}
&{p_N}^1-{p_N}^2={p_N}^3-{p_N}^4=\frac{\mu^d\,\Delta_\tau-t+\Delta_c}{4},\\
&{p_N}^1-{p_N}^3={p_N}^2-{p_N}^4=\frac{\mu^c\,\Delta_\tau-t+\Delta_c}{4},\\
&{p_N}^1-{p_N}^4=\frac{(\mu^d+\mu^c)\,\Delta_\tau-2\,t+2\,\Delta_c}{4},\\
&{p_N}^2-{p_N}^3={p_S}^2-{p_S}^3=-\frac{\Delta_\mu\,\Delta_\tau}{4}<0,\\
&{p_S}^1-{p_S}^2={p_S}^3-{p_S}^4=\frac{\mu^d\,\Delta_\tau+t+\Delta_c}{4}>0,\\
&{p_S}^1-{p_S}^3={p_S}^2-{p_S}^4=\frac{\mu^c\,\Delta_\tau+t+\Delta_c}{4}>0,\\
&{p_S}^1-{p_S}^4=\frac{(\mu^d+\mu^c)\,\Delta_\tau+2\,t+2\,\Delta_c}{4}>0.
\end{aligned}
$$

E Proof of Proposition 3

Once again, to determine the effects of the offshoring we have to compare case 1 to cases 2 and 3, and cases 2 and 3 to case 4. It is clear if there is only one firm located in the North (case 2 and 3), if the firm relocates (case 4), tax revenue decreases and falls to zero. Hence, to compare the effects of offshoring on tax revenue, we still have to compare case 1 to cases 2 and 3, and case 2 to 3.

$TR^1-TR^2=\mu^c\,r_N^{c_1}+\mu^d\,r_N^{d_1}-\mu^c\,r_N^{c_2}=\mu^c\,(r_N^{c_1}-r_N^{c_2})+\mu^d\,r_N^{d_1}$, from $r_N^{c_1}-r_N^{c_2}=\frac{\mu^d\,\Delta_\tau+\Delta_c}{2}>0$, $TR^1>TR^2$.
$TR^1-TR^3=\mu^c\,r_N^{c_1}+\mu^d\,r_N^{d_1}-\mu^d\,r_N^{d_3}=\mu^c\,r_N^{c_1}+\mu^d\,\left(r_N^{d_1}-r_N^{d_3}\right)$, from $r_N^{d_1}-r_N^{d_3}=\frac{\mu^c\,\Delta_\tau+\Delta_c}{2}>0$, $TR^1>TR^3$.
Offshoring, regardless of the type of firms that relocates, decreases tax revenue.
We now compare the difference in tax revenue if a dirty or a clean firm relocates to the South:

$$TR^2-TR^3=\mu^c\,r_N^{d_2}-\mu^d\,r_N^{d_3}=\frac{\Delta_\mu\,(6\,\tau_N\,(\mu^d+\mu^c)-2\,\mu^d\,\tau_S+t+6\,c_N-4\,c_S-a_N-a_S)}{4} \quad (11)$$

We study how this difference is affected by the parameters: $\frac{\partial\,(11)}{\partial\,t}=\frac{\Delta_\mu}{4}$; $\frac{\partial\,(11)}{\partial\,c_N}=\frac{3\,\Delta_\mu}{2}$; $\frac{\partial\,(11)}{\partial\,c_S}=-\Delta_\mu$; ; $\frac{\partial\,(11)}{\partial\,\tau_S}=-\frac{\mu^d\,\Delta_\mu}{2}$; $\frac{\partial\,(11)}{\partial\,a_N}=\frac{\partial\left(\mu^c\,r_N^{d_2}-\mu^d\,r_N^{d_3}\right)}{\partial\,a_S}=-\frac{\Delta_\mu}{4}$; $\frac{\partial\,(11)}{\partial\,\tau_N}=\frac{3\,\Delta_\mu\,(\mu^d+\mu^c)}{2}$.

F Proof of Proposition 4

Once again, to determine the effects of the offshoring we have to compare case 1 to cases 2 and 3, and cases 2 and 3 to case 4. It is clear if there is only one firm located in the

North (case 2 and 3), if the firm relocates (case 4), northern profit decreases and falls to zero. Hence, to compare the effects of offshoring on northern profit, we still have to compare case 1 to cases 2 and 3, and case 2 to 3.

Let us first study the effect of the offshoring of a dirty firm:
The offshoring of a dirty firm decreases the northern profit if $\pi_N^1 = \pi_N^{c_1} + \pi_N^{d_1} > \pi_N^{c_2}$, that is if $\pi_N^{c_1} - \pi_N^{c_2} > 0$.

$\pi_N^{c_1} - \pi_N^{c_2} = {r_{NN}^{c_1}}^2 - {r_{NN}^{c_2}}^2 + {r_{NS}^{c_1}}^2 - {r_{NS}^{c_2}}^2 = \left(r_{NN}^{c_1} - r_{NN}^{c_2}\right)\,\left(r_{NN}^{c_1} + r_{NN}^{c_2}\right) + \left(r_{NS}^{c_1} - r_{NS}^{c_2}\right)\,\left(r_{NS}^{c_1} + r_{NS}^{c_2}\right).$

Using, $r_{NN}^{c_1} - r_{NN}^{c_2} = \frac{\mu^d\,\Delta_\tau + \Delta_c - t}{4}$ and $r_{NS}^{c_1} - r_{NS}^{c_2} = \frac{\mu^d\,\Delta_\tau + \Delta_c + t}{4}$, we obtain:

$$\pi_N^{c_1} - \pi_N^{c_2} = \frac{\mu^d\,\Delta_\tau + \Delta_c}{4}\,\left(r_{NN}^{c_1} + r_{NN}^{c_2} + r_{NS}^{c_1} + r_{NS}^{c_2}\right) + \frac{t}{4}\,\left(r_{NS}^{c_1} + r_{NS}^{c_2} - r_{NN}^{c_1} - r_{NN}^{c_2}\right).$$

Since $r_{NS}^{c_1} + r_{NS}^{c_2} - r_{NN}^{c_1} - r_{NN}^{c_2} = \frac{a_S - a_N - 4\,t}{2}$, if $a_S - a_N - 4\,t > 0$, the northern profits decrease with offshoring. If $a_S - a_N - 4\,t < 0$, the northern profits may increase with offshoring (necessary but not sufficient condition).

Let us now study the effect of the offshoring of a clean firm:
The offshoring of a clean firm decreases the northern profit if $\pi_N^1 = \pi_N^{c_1} + \pi_N^{d_1} > \pi_N^{d_3}$, that is if $\pi_N^{d_1} - \pi_N^{d_3} > 0$.

$\pi_N^{d_1} - \pi_N^{d_3} = {r_{NN}^{d_1}}^2 - {r_{NN}^{d_3}}^2 + {r_{NS}^{d_1}}^2 - {r_{NS}^{d_3}}^2 = \left(r_{NN}^{d_1} - r_{NN}^{d_3}\right)\,\left(r_{NN}^{d_1} + r_{NN}^{d_3}\right) + \left(r_{NS}^{d_1} - r_{NS}^{d_3}\right)\,\left(r_{NS}^{d_1} + r_{NS}^{d_3}\right).$

Using, $r_{NN}^{d_1} - r_{NN}^{d_3} = \frac{\mu^c\,\Delta_\tau + \Delta_c - t}{4}$ and $r_{NS}^{d_1} - r_{NS}^{d_3} = \frac{\mu^c\,\Delta_\tau + \Delta_c + t}{4}$, we obtain:

$$\pi_N^{d_1} - \pi_N^{d_3} = \frac{\mu^c\,\Delta_\tau + \Delta_c}{4}\,\left(r_{NN}^{d_1} + r_{NN}^{d_3} + r_{NS}^{d_1} + r_{NS}^{d_3}\right) + \frac{t}{4}\,\left(r_{NS}^{d_1} + r_{NS}^{d_3} - r_{NN}^{d_1} - r_{NN}^{d_3}\right).$$

Since $r_{NS}^{d_1} + r_{NS}^{d_3} - r_{NN}^{d_1} - r_{NN}^{d_3} = \frac{a_S - a_N - 4\,t}{2}$, if $a_S - a_N - 4\,t > 0$, the northern profits decrease with offshoring. If $a_S - a_N - 4\,t < 0$, the northern profits may increase with offshoring (necessary but not sufficient condition).

Let us now compare the offshoring of a clean firm to the offshoring of a dirty firm in terms of northern profits:

$\pi_N^{c_2} - \pi_N^{d_3} = {r_{NN}^{c_2}}^2 - {r_{NN}^{d_3}}^2 + {r_{NS}^{c_2}}^2 - {r_{NS}^{d_3}}^2 = \left(r_{NN}^{c_2} - r_{NN}^{d_3}\right)\,\left(r_{NN}^{c_2} + r_{NN}^{d_3}\right) + \left(r_{NS}^{c_2} - r_{NS}^{d_3}\right)\,\left(r_{NS}^{c_2} + r_{NS}^{d_3}\right)$

which is strictly positive from $r_{NN}^{c_2} - r_{NN}^{d_3} = r_{NS}^{c_2} - r_{NS}^{d_3} = \frac{\Delta_\mu\,(3\,\tau_N + \tau_S)}{4}$.