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Dirty versus Clean Firms' Relocation under International Trade and Imperfect Competition

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Abstract. This paper develops a simple partial equilibrium model with two countries (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 clean technology and a dirty one, and the effects of relocation according to the kind of technology used by the relocated firms are determined. Two heterogeneous firms in the North and only one dirty firm in the South are assumed and the four different possible scenarios are compared: neither firm relocates, the two northern firms relocate, the clean one relocates and the dirty one relocates. This paper demonstrates that 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. Moreover, the relocation of a dirty firm always increases global emissions, while the relocation of a clean firm may decrease global emissions.

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

JEL codes. L13, Q53, Q58.

1. Introduction

Climate change requires significant efforts by countries to reduce greenhouse gas emissions. However, as demonstrated by the different rounds of COP negotiations, developing countries expect greater efforts from developed countries because the latter have higher levels of wealth and access to more advanced technologies on average. If developed countries implement more stringent regulations than developing countries to reduce emissions, the competitiveness of developed countries' firms will decrease and they could relocate their production to developing countries. Nevertheless, there is great heterogeneity in production technologies and some

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are less polluting than others. There is a technological asymmetry between developed and developing countries but also within developed countries. For instance, 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 is then questionable whether the most polluting firms are the ones most likely to relocate and it therefore seems interesting to examine the effects of relocations depending on whether the technology used is environmentally-friendly or not.

Relocation can be detrimental to a country because it leads to job losses, increased unemployment and the destruction of physical and human capital, inducing a loss of specific knowledge and skills. Rising unemployment generates costs (unemployment benefits, operation of job-search agencies and expenditure induced by the social consequences of unemployment in areas such as housing and health) but also deficits (in taxes and social contributions). Political effects are also induced by unemployment, such as the development of a sense of exclusion for the unemployed. Relocation can also be detrimental for the environment since firms that relocate in countries implementing more lenient environmental regulations, may contribute to increasing emissions by producing more (see for instance Taylor (2015) and the literature on pollution havens). However, to our knowledge, this literature does not study the role of the environmental quality of the technologies used on the effects of firm relocations.

Our analysis also takes into account the role of international trade and imperfect competition. Today's economies are globalized and firms are important players in these international exchanges. The most polluting sectors are also oligopolistic sectors.[1] Without international trade, relocation makes the market more concentrated and reduces the social surplus. However, in the presence of bilateral trade, relocation does not necessarily reduce the number of competitors in a market since relocated firms can always supply their home market by exporting the goods. Thus, firm relocations alter market structures and competition in different countries. In the presence of imperfect competition, relocation changes the exercise of market power by firms.

We consider two different production technologies, a clean technology and a dirty one and compare the effects of relocation according to the kind of technology used by the relocated firm. We develop a simple partial equilibrium model with two countries (North and South) to fathom the effects of firms' relocation in a context of international and imperfect competition. The model describes the interactions between the two regions, each of which implements a different emissions tax. In each region, firms produce the same homogeneous polluting good. The cleanliness of a firm is given by its emissions intensity, that is the number of emissions by unit produced. We assume that the northern economy is more advanced than the southern economy, in the sense that in this region, relatively clean firms and dirty firms coexist, while in the South, there are only dirty firms. Moreover, in the North economy, 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

[1] See for instance, Requate (2005), Katsoulacos and Xepapadeas (1995), or Ulph (1996).

more expensive in advanced economies.

We assume that firms in the North may decide to relocate to the other region at a fix and symmetric cost. By relocating its production, a northern firm benefits from lower production cost and is subject to the southern environmental regulation. We assume two heterogeneous firms in the North and only one dirty firm in the South. We compare the four possible different scenarios in order to emphasize the effects of relocation: neither firm relocates, the two northern firms relocate, the clean one relocates and the dirty one relocates.

The paper shows that 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. The northern welfare decreases with the relocation of a dirty firm when the marginal environmental damage is sufficiently great. However, it only decreases with the relocation of a clean firm when the technological gap is sufficiently low and the marginal environmental damage is sufficiently great. Indeed, the relocation of a dirty firm always increases global emissions, while the relocation of a clean firm may decrease global emissions. The relocation of a dirty firm is better in terms of welfare than a clean one when the marginal production cost in the South, the market-size in the two countries are great and when the marginal production cost in the North, the transportation cost and the marginal environmental damage are low.

The current paper relates to the literature studying the relocation of firms into countries without environmental regulations or with less stringent regulations, such as Motta and Thisse (1994), Markusen et al. (1993), Greaker (2003); Petrakis and Xepapadeas (2003) or Sanna-Randaccio et al. (2017). More specifically, the paper contributes to the literature analyzing the social effects of relocation due to environmental regulation and studying the implementation of the optimal policies. Martin et al. (2014) in a seminal paper defines the damage of relocation. They express damages in terms of both CO_2 emissions and jobs lost due to relocation. For instance, Bartik (2015) estimates the social costs of jobs lost due to various environmental regulations in the United States at between 8 and 32 percent of the associated earnings. In this paper, we adopt a welfare analysis to determine the costs of relocation and also determine the redistributive effects of relocation

This paper also contributes to the literature focusing on technology diffusion. Indeed, clean firms' relocation is one of the different ways to diffuse technology. Relocations participate to international technology diffusion when relocated firms use more efficient technology than firms in the host country. Several papers highlight the potential perverse effects of technology diffusion. Ing and Nicolaï (2019) emphasize that technology diffusion reduces the incentives to relocate. Stranlund (1996) demonstrates that technology diffusion does not necessarily improve the environment and consequently the welfare. Our paper is complementary since we compare the effects of relocation according to the kind of production technology used and show the conditions under which it is preferable that the firm which relocates is a clean one instead of a dirty one.

The paper is structured as follows. Section 2 presents the modeling assumptions and compares the different scenarios in terms of welfare. Section 3 discusses the robustness of the results, derives some policy implications and concludes.

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.

The goal of this paper is to emphasize the role of imperfect competition on the effects of relocation. Therefore, firms are assumed to compete "à la Cournot" in each market. We focus on the case of two heterogeneous firms in the North and only one firm in the South.

The production of the good is polluting and generates emissions which are harmful. We consider global pollution, hence the location of production has no effect on the damage caused to the environment. 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. Finally, we obviously assume that $\Delta_\mu = \mu^d - \mu^c > 0$. We consider that one northern firm is clean (it owns the clean technology) and the other northern 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. It is not possible to copy in the North because of intellectual property protection. However, we will later discuss the case in which in the South clean firms can be copied.

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. The production costs can be interpreted as production costs. We assume that the production costs are higher in the northern economy than in the southern one, that is $\Delta_c = c_N - c_S > 0$.

Each firm is assumed to sell on the two markets. Transport is costly and let t be the constant unit transportation cost. The production of a 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 a southern dirty (clean) firm i, sold respectively in the northern and in the southern market.

In each country, an emissions tax is introduced to reduce emissions. 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.

The firms in the North may relocate in the South. We assume a symmetric fixed cost of relocation C^R. A northern firm relocates its production if, and only if, the profit that it will realize in the South net of relocation costs is higher than the current profit made in the North.

In this paper, we analyze the effects of relocation in terms of price, profits, total emissions, tax revenues and welfare, by focusing on the technology used by the relocating firm. To do so, we compare the four possible different scenarios in order to emphasize the effects of relocation: neither firm relocates, the dirty one relocates, the clean one relocates, and the two northern firms relocate.

2.2. The different scenarios

We consider four different cases: the business-as-usual, only the dirty firm relocates , only the clean firm relocates and both firms relocate.

The business-as-usual case. In the business-as-usual case, 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 firms have to pay the emissions tax in the North even for products sold in the South. The production of one unit generates a respective unit cost of $\tau_N\, \mu^c + c_N$ for the clean firm and $\tau_N\, \mu^d + c_N$ for the dirty one. Units sold in the South require payment of the transportation cost.

The southern firm solves the following problem:

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

Each production unit incurs a unit cost of $c_S + \tau_S\, \mu^d$ which consists of the wage cost c_S and the cost related to the environmental tax $\tau_S\, \mu^d$. Each unit sold in the South induces an additional unit transportation cost. By calculating the first-order conditions and solving the system of equations, we obtain the productions and prices at equilibrium, which are detailed in Appendix A.1. The superscript 1 refers to this case.

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. Moreover, firms have an advantage on their domestic market since they do not pay the transportation cost when they supply their local market.

Only the dirty firm relocates. 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 clean firm solves the following problem:

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

The two dirty firms solve the following problem:

$$\max_{r^d_{SS}, r^d_{SN}} \; \pi^d_F = (p_S - c_S - \tau_S\,\mu^d)\, r^d_{SS} + (p_N - c_N - \tau_S\,\mu^d - t)\, r^d_{SN}. \tag{5}$$

By calculating the first-order conditions and solving the system of equations, we obtain the productions, which are detailed in Appendix A.2. The superscript 2 refers to this case.

Depending on the transportation cost, the emissions tax, and the production cost, the clean firm may produce more or less than the dirty southern firms. Once again, the clean firm uses a more efficient technology but faces higher tax and production costs. Moreover, if the parameters are such that the southern firms produce individually more than the northern firm in the northern market, then they necessarily produce more on the southern market.

Only the clean firm relocates. The northern firm uses the dirty technology, while in the South the two technologies coexist. The three firms sell in the North and in the South. 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:

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

The dirty firm in the South solve the following problem:

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

By calculating the first-order conditions and solving the system of equations, we obtain the productions, which are detailed in Appendix A.3. The superscript 3 refers to this case. 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 clean firm and the dirty firm relocate. The three firms produce in the South. One firm uses the clean technology, while the two others own the dirty technology. The three firms sell in the North and in the South. The clean firm solves the following problem:

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

The two dirty firms solve the following problem:

$$\max_{r^d_{SS_i}, r^d_{SN_i}} \pi^d_{F_i} = (p_S - c_S - \tau_S\,\mu^d)\, r^d_{SS_i} + (p_N - c_S - \tau_S\,\mu^d - t)\, r^d_{SN_i}. \tag{10}$$

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. By calculating the first-order conditions and solving the system of equations, we obtain the productions and prices at equilibrium, which are detailed in Appendix A.4. The superscript 4 refers to this case. The two dirty firms produce the same, while the clean firm produces more since its marginal cost is lower. The productions and the prices obviously do not depend on the northern environmental tax.

Once we have presented the four possible market structures we can study the incentives for each firm to relocate and show that the four market structures can occur.

Incentives to relocate Let us now compare the incentive of the clean and the dirty firm to relocate. The following equation illustrates the conditions under which the clean firm has higher incentives to relocate than the dirty one:

$$\pi^{c3}_S - \pi^{c1}_N - C_R \geqslant \pi^{d2}_S - \pi^{d1}_N - C_R, \tag{11}$$

where the left-hand side of the equation corresponds to the incentives of the clean firm to relocate and the right-hand side corresponds to those of the dirty firm. It is assumed here that each firm anticipates that relocation alters market structure but does not anticipate that the other firm may also relocate. Relocating is a long process and we assume that firms' decisions to relocate are sequential.[2] From equation (11), the following lemma is deduced.

Lemma 1. *The clean firm may have more or less incentive to relocate than the dirty one.*

Proof. The proof, Appendix B. □

Clean firms produce more after relocation 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. Lemma 1 is particularly interesting since the literature studying pollution havens considers that the dirtiest firms are those that relocate first. We show that this assessment is not always true and therefore justifies that we compare the four cases mentioned above.

[2] Another explanation could be that firms are myopic.

By studying (11), a clean firm has more incentive to relocate than a dirty firm when the transportation cost t and the production costs gap Δ_c are great, and when the market sizes are low. In other words, a clean firm has more incentive to relocate than a dirty firm when southern firms are highly competitive.

2.3. The comparison of scenarios

The purpose of this section is to compare the four scenarios in terms of welfare. First, we analyze the effects of relocation on the four components of welfare, which are the environmental damage, the consumer surplus, the profits and the regulator's revenue.

The global emissions are equal to the sum of the production of each firm times its emission intensity. The following proposition compares the effects of relocation on the global emissions.

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

- *the relocation of a dirty firm increases emissions, while the relocation of a clean firm only increases emissions if the emission intensity of the dirty technology is sufficiently low relatively to the clean technology's one,*
- *if the two firms relocate, emissions then unambiguously increase,*
- *emissions are higher when the dirty firm relocates than when the clean firm relocates.*

Proof. The proof, Appendix C. □

Relocation affects global 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 relocating, 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.

Global emissions always increase with the relocation 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, emissions only increase with the relocation of a clean firm if $3\,\mu^c - 2\,\mu^d > 0$, hence the indirect effect may dominate the direct one. Indeed, since dirty firms react to the relocation of a clean one by decreasing their production, relocation improves the environment when μ^d is relatively large. On the opposite, since the relocated clean firm increases its production, relocation deteriorates the environment when μ^c is relatively great. Hence, the relocation of a clean firm is detrimental for the environment when the technological gap is relatively low.

Global 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. Moreover, since it uses a dirtier technology, the increase in 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. Hence, the relocation of a clean firm is better for the environment than the relocation of a dirty firm.

Note that the barriers to trade are captured by the parameter t, which is the transportation cost. Global emissions decrease with the transportation cost in each of the four cases. However, the differences in emissions between the different scenarios ($E^1 - E^2$ and $E^1 - E^3$) do not depend on the transportation cost. We deduce that trade policies cannot be used to mitigate the negative effects of relocation on the environment.

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 relocation on the northern consumer surplus.

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

- *the northern consumer surplus increases with relocation 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. The proof, Appendix D □

If the transportation cost is low, the relocation induces then a decrease in the northern price, since the relocated firm benefits from a lower production cost and a lower emissions tax. Indeed, if the transportation cost is low, relocation makes then a northern firm more efficient since its marginal production cost will be lower. Therefore, the relocated firm produces more than in the business-as-usual case 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 in the business-as-usual case. 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.

Relocation 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 clean firm relocates than when a dirty firm relocates. Hence, the southern consumers benefits from having a more firms producing in the South. They benefit even more when firms are efficient.

Let us focus on the northern tax revenue, which is equal to the northern emissions times the emission tax in the North. The following proposition determines the effects of relocation on the northern tax revenue.

PROPOSITION 3. *The effect of relocation on the northern tax revenue depends on the type of relocated firm:*

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

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

Proof. The proof, Appendix E □

The relocation of either a dirty or a clean firm decreases the northern tax revenue since the total northern emissions decreases with relocation. Nevertheless, the tax revenue may be either higher or lower in the dirty firm relocation case than in the clean firm's relocation 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 relocation on the sum of northern profits.

PROPOSITION 4. *The effect of relocation on the sum of northern profits depends on the type of relocated firm:*

- *relocation always decreases northern profit if the transportation cost is relatively low,*

- *relocation may increase northern profit if the transportation cost are 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. The proof, Appendix F □

The effect of relocation on northern profits is threefold: the profit of the relocated firm disappears, the profit of the remaining firm on the southern market decreases since the relocated firm benefits from low production costs and a low tax and also saves on transportation cost. Finally, the profit of the remaining firm on the northern market increases if the transportation cost is high enough. Hence, if the transportation cost is low, relocation always decreases northern profit. The profits of a firm that uses technology k increase with relocation if and only if $t > \mu^k \Delta_\tau + \Delta_c$ and if the effect on the southern market prevails.

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, that is when a clean firm remains in the North than when it relocates.

Let us sum up the redistributive effects of relocation. Relocation always decreases the tax revenue. The effect of relocation on the other components of the northern welfare - consumer surplus, environmental damage, profits - depends on the level of transportation cost and the technological gap.

If $t < \mu^d \Delta_\tau + \Delta_c$, the transportation cost is then relatively low and international competition is intense. The relocation of a firm regardless of its type decreases the northern price and profits. Hence, relocation is detrimental for the northern economy (production and profits) but benefit to consumers since they can export cheaper goods.[3]

If $t > \mu^d \Delta_\tau + \Delta_c$, the transportation cost is then relatively great and firms have a strong advantage on their local market. The relocation of a firm regardless of its type increases the northern price since transport is expensive. The effect on total profits is ambiguous. On the one hand, there are less firms and the firm that remains in the North loses sales in the southern market, however these losses can be compensated by an increase in sales in the northern market. Hence, the relocation is detrimental for consumers but may benefit to the Northern economy.

Finally, the relocation of a dirty firm increases global emissions, while the relocation of a clean firm increases emissions if and only if the technological gap is low $(2\,\mu^d - 3\,\mu^c < 0)$.

In order to study the effects of relocation on the aggregated welfare, let us consider from now a constant marginal damage. The marginal damage in country l is denoted by δ_l. The following proposition determines how relocation affects welfare.

PROPOSITION 5. *The effect of relocation on the northern welfare depends on the type of relocated firm:*

- *the northern welfare decreases with the relocation of a dirty firm when the marginal environmental damage is sufficiently great,*
- *the northern welfare decreases with the relocation of a clean firm when the technological gap is sufficiently low and the marginal environmental damage is sufficiently great,*
- *the relocation of a dirty firm is better in terms of welfare than a clean one when the marginal production cost in the South, and the market-size in the two countries are great and when the marginal production cost in the North, the transportation cost and the marginal environmental damage are low.*

Proof. The proof, Appendix G □

The first two statements in Proposition 5 are immediately deducted from the previous results. Let us therefore focus on the third one. In what follows, we study how the parameters affect the difference in welfare $(W_N^2 - W_N^3)$.

[3] $t < \mu^d \Delta_\tau + \Delta_c$ implies $t < \mu^c \Delta_\tau + \Delta_c$, the threshold on the transportation cost below which relocation decreases price and profit is lower for a clean firm.

As the market size increases, the production, and thus the tax revenue and the profit increases. With large market sizes, the tax revenue from a dirty firm is high, and this calls for the relocation of a clean firm. On the opposite, since the profit from a clean firm is high, this calls for a dirty firm's relocation. Nevertheless, the second effect dominates and as the market sizes increase the welfare tends to be higher when a dirty firm relocates than when a clean one relocates. This effect is amplified by the effect on consumer surplus. Indeed, if the maximal willingness to pay in the North is high, the consumers in the North will then highly benefit from the low price induced by a dirty firm's relocation. Note that the market sizes do not affect the differences in emissions.

The gains in terms of profits and consumer surplus are higher when a dirty firm relocates than when a clean firm relocates, however, these gains decrease as transportation cost increases. Moreover, as the transportation cost increases, the production decreases and it becomes more beneficial to tax a clean firm. Hence, as the transportation cost increases the government is better off when a clean firm relocates.

As the difference in production cost between the two countries (Δ_c) increases the relocated firm competitiveness increases, and the harmful effect on the environment induced by the relocation of a dirty firm is amplified. Moreover, the profit loss related to a clean firm's relocation versus a dirty firm relocation shrinks. On the opposite side, as the difference in production cost increases, since the relocated firm will be more competitive, the potential benefits from keeping a dirty firm in terms of tax revenue decreases, while the potential benefits from keeping a clean firm in terms of tax revenue increases. Taking these effects all together, as the the difference in production cost increases the northern welfare is higher when a clean firm relocates.

Finally, since global emissions are higher when a dirty firm relocates, as the marginal environmental damage increases the northern welfare tends to be higher when a clean firm relocates than when a dirty firm relocates.

3. Discussion and Concluding Remarks

This short paper demonstrates that 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 domestic profits. When the marginal environmental damage is sufficiently high and the technological gap is sufficiently low any relocation decreases the northern welfare. The relocation of a dirty firm is better in terms of welfare than a clean one when the marginal production cost in the South, the market-size in the two countries are great and when the marginal production cost in the North, the transportation cost and the marginal environmental damage are low.

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. Contrary to what is claimed by the pollution haven literature, clean firms may have more incentives to relocate than dirty firms. Relocation of clean and dirty firms does not have the same distributive effects. From a normative point of view, when the environmental damage is large enough, the regulator has an interest in preventing dirty firms from relocating. Moreover, when the technological gap is sufficiently low and the marginal environmental damage is sufficiently great, the regulator has an incentive in preventing clean firms from relocating. This can be done by distributing subsidies to reduce incentives to relocate. To reduce the cost of such a policy, it is useful to differentiate the distribution of subsidies according to technology. In a case where the regulator is financially constrained and cannot disburse sufficient sums to prevent all firms from relocating, a choice may arise between protecting clean or dirty firms. Thus, if the marginal environmental damage is particularly significant, the regulator will prefer that dirty firms remain in the North.

An important result of the current paper is that, under great technological gap, the relocation of a clean firm reduces overall emissions. The relocation of a clean firm entails the diffusion of technology in developing countries, while the relocation of a dirty firm always leads to an increase in global emissions. Put differently, the relocation of firms with technological advantages is one of the main channels for the diffusion of technology (see Glachant and Dechezleprêtre (2017)) which may decrease emissions.

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, relocation of a clean firm can lead to spillovers. In other words, when the technology spreads among southern firms, the latter will be able to use a cleaner technology without purchasing any patents. Hence, the spillovers strengthens the competition in both markets. As a result, the northern consumers will be better off, the profit 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, it decreases the production and the emissions of both the relocated firm and the northern dirty firm, and on the other hand, it increases the production of the former-dirty firm.

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 incentive to relocate, 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. Assume 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 robust with the presence of several dirty and several clean firms.

The model developed in this paper could also be used to study the long-run equilibrium, i.e. by endogenizing relocation decisions. In other words, we have studied and compared the different possible market organizations but we have not studied the long-term market organizations. The paper's objective is to study to what extent the environmental quality of the technology used by the relocating firm is important to understand the effects of relocation. However, we could analyze which market organization is emerging in the long-run. For example, it would be interesting to analyze the optimal environmental policy by taking into account the long-run effects.

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Appendixes

A. The productions and the prices at equilibrium under the four different scenarios

A.1. The business-as-usual case

$$r^{d1}_{SN} = \frac{\mu^d\,\tau_N + \mu^c\,\tau_N - 3\,\mu^d\,\tau_S - 3\,t + 2\,c_N - 3\,c_S + a_N}{4}$$
$$r^{c1}_{NN} = \frac{\mu^d\,\tau_N - 3\,\mu^c\,\tau_N + \mu^d\,\tau_S + t - 2\,c_N + c_S + a_N}{4}$$
$$r^{d1}_{NN} = \frac{\mu^c\,\tau_N - 3\,\mu^d\,\tau_N + \mu^d\,\tau_S + t - 2\,c_N + c_S + a_N}{4}$$
$$r^{d1}_{SS} = \frac{\mu^d\,\tau_N + \mu^c\,\tau_N - 3\,\mu^d\,\tau_S + 2\,t + 2\,c_N - 3\,c_S + a_S}{4}$$
$$r^{d1}_{NS} = \frac{\mu^c\,\tau_N - 3\,\mu^d\,\tau_N + \mu^d\,\tau_S - 2\,t - 2\,c_N + c_S + a_S}{4}$$
$$r^{c1}_{NS} = \frac{\mu^d\,\tau_N - 3\,\mu^c\,\tau_N + \mu^d\,\tau_S - 2\,t - 2\,c_N + c_S + a_S}{4}$$

The equilibrium prices are:

$$p^1_N = \frac{\mu^d\,\tau_N + \mu^c\,\tau_N + \mu^d\,\tau_S + t + 2\,c_N + c_S + a_S}{4}$$
$$p^2_S = \frac{\mu^d\,\tau_N + \mu^c\,\tau_N + \mu^d\,\tau_S + 2\,t + 2\,c_N + c_S + a_S}{4}$$

$r^{d1}_{SN} - r^{c1}_{NN} = \mu^c\,\tau_N - \mu^d\,\tau_S + \Delta_c - t$, $r^{d1}_{SN} - r^{d1}_{NN} = \mu^d\,\Delta_\tau + \Delta_c - t$,
$r^{c1}_{NN} - r^{d1}_{NN} = r^{c1}_{NS} - r^{d1}_{NS} = \Delta_\mu\,\tau_N$, $r^{d1}_{SS} - r^{d1}_{NS} = \mu^d\,\Delta_\tau + \Delta_c + t$, $r^{d1}_{SS} - r^{c1}_{NS} = \mu^c\,\tau_N - \mu^d\,\tau_S + \Delta_c + t$.

The emissions are:

$$E^1 = \frac{2\,(2\,\mu^d - \mu^c)\,(\mu^c\,\tau_N - \mu^d\,(\tau_N + \tau_S) - c_S) - 4\,\mu^c\,(\mu^c\,\tau_N + c_N) - (2\,\mu^d + \mu^c)\,(t - a_N - a_S)}{4}$$

A.2. Only the dirty firm relocates

The production levels are:

$$r^{d2}_{SN} = \frac{\mu^c\,\tau_N - 2\,\mu^d\,\tau_S - 2\,t + c_N - 2\,c_S + a_N}{4}$$
$$r^{c2}_{NN} = \frac{2\,\mu^d\,\tau_S - 3\,\mu^c\,\tau_N + 2\,t - 3\,c_N + 2\,c_S + a_N}{4}$$
$$r^{d2}_{SS} = \frac{\mu^c\,\tau_N - 2\,\mu^d\,\tau_S + t + c_N - 2\,c_S + a_S}{4}$$
$$r^{c2}_{NS} = \frac{2\,\mu^d\,\tau_S - 3\,\mu^c\,\tau_N - 3\,t - 3\,c_N + 2\,c_S + a_F}{4}$$

The equilibrium prices are:

$$p^2_N = \frac{\mu^c\,\tau_N + 2\,\mu^d\,\tau_S + 2\,t + c_N + 2\,c_S + a_N}{4}$$
$$p^2_S = \frac{\mu^c\,\tau_N + 2\,\mu^d\,\tau_S + t + c_N + 2\,c_S + a_S}{4}$$

$r^{d2}_{SN} - r^{c2}_{NN} = \mu^c\,\tau_N - \mu^d\,\tau_S - t + \Delta_c$, $r^{d2}_{SS} - r^{c2}_{NS} = \mu^c\,\tau_N - \mu^d\,\tau_S + t + \Delta_c$

The emissions are:

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

A.3. Only the clean firm relocates

The production levels are:

$$r^{c3}_{SS} = \frac{\mu^d\,\tau_N + \mu^d\,\tau_S - 3\,\mu^c\,\tau_S + t + c_N - 2\,c_S + a_S}{4}$$
$$r^{d3}_{SS} = \frac{\mu^d\,\tau_N - 3\,\mu^d\,\tau_S + \mu^c\,\tau_S + t + c_N - 2\,c_S + a_S}{4}$$
$$r^{d}_{NS} = \frac{\mu^d\,\tau_S - 3\,\mu^d\,\tau_N + \mu^c\,\tau_S - 3\,t - 3\,c_N + 2\,c_S + a_S}{4}$$
$$r^{c3}_{SN} = \frac{\mu^d\,\tau_N + \mu^d\,\tau_S - 3\,\mu^c\,\tau_S - 2\,t + c_N - 2\,c_S + a_N}{4}$$
$$r^{d3}_{SN} = \frac{\mu^d\,\tau_N - 3\,\mu^d\,\tau_S + \mu^c\,\tau_S - 2\,t + c_N - 2\,c_S + a_N}{4}$$
$$r^{d3}_{NN} = \frac{\mu^d\,\tau_S - 3\,\mu^d\,\tau_N + \mu^c\,\tau_S + 2\,t - 3\,c_N + 2\,c_S + a_N}{4}$$

The equilibrium prices are:

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

$r_{SN}^{c3} - r_{SN}^{d3} = r_{SS}^{c3} - r_{SS}^{d3} = \Delta_\mu\,\tau_S$, $r_{SN}^{d3} - r_{NN}^{d3} = \mu^d\Delta_\tau + \Delta_c - t$, $r_{SN}^{c3} - r_{NN}^{d3} = \mu^d\,\tau_N - \mu^c\,\tau_S + \Delta_c - t$, $r_{SS}^{d3} - r_{NS}^{c3} = \mu^d\Delta_\tau + \Delta_c + t$, $r_{NS}^{c3} - r_{SS}^{d3} = \mu^d\,\tau_N - \mu^c\,\tau_S + \Delta_c + t$.

The emissions are:

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

A.4. The clean firm and the dirty firm relocate

The production levels are:

$$r_{SN}^{c4} = \frac{2\,\mu^d\,\tau_S - 3\,\mu^c\,\tau_S - t - c_S + a_N}{4}$$
$$r_{SN}^{d4} = \frac{\mu^c\,\tau_S - 2\,\mu^d\,\tau_S - t - c_S + a_N}{4}$$
$$r_{SS}^{c4} = \frac{2\,\mu^d\,\tau_S - 3\,\mu^c\,\tau_S - c_S + a_S}{4}$$
$$r_{SS}^{d4} = \frac{\mu^c\,\tau_S - 2\,\mu^d\,\tau_S - c_S + a_F}{4}$$

The equilibrium prices are:

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

$r_{SN}^{c4} - r_{SN}^{d4} = r_{SS}^{c4} - r_{SS}^{d4} = \Delta_\mu\,\tau_S$.

The emissions are:

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

B. Proof of Lemma 1

Clean firm's incentive:

$$\begin{aligned}\pi_S^{c3} - \pi_N^{c1} - C_R &= {r_{SS}^{c3}}^2 - {r_{NS}^{c1}}^2 + {r_{SN}^{c3}}^2 - {r_{NN}^{c1}}^2 - C_R \\ &= (r_{SS}^{c3} - r_{NS}^{c1})\,(r_{SS}^{c3} + r_{NS}^{c1}) + (r_{SN}^{c3} - r_{NN}^{c1})\,(r_{SN}^{c3} + r_{NN}^{c1}) - C_R\end{aligned}$$

Using $r_{SS}^{c3} - r_{NS}^{c1} = \frac{3\,(\mu^c\,\Delta_\tau + \Delta_c + t)}{4}$ and $r_{SN}^{c3} - r_{NN}^{c1} = \frac{3\,(\mu^c\,\Delta_\tau + \Delta_c - t)}{4}$

$$\pi_S^{c3} - \pi_N^{c1} - C_R = \frac{3\,(\mu^c\,\Delta_\tau + \Delta_c)}{4}\,(r_{SS}^{c3} + r_{NS}^{c1} + r_{SN}^{c3} + r_{NN}^{c1}) + \frac{3\,(a_N - a_S)\,t}{8} - C_R$$

Dirty firm's incentive:

$$\begin{aligned}\pi_S^{d2} - \pi_N^{d1} - C_R &= {r_{SS}^{d2}}^2 - {r_{NS}^{d1}}^2 + {r_{SN}^{d2}}^2 - {r_{NN}^{d1}}^2 - C_R \\ &= (r_{SS}^{d2} - r_{NS}^{d1})\,(r_{SS}^{d2} + r_{NS}^{d1}) + (r_{SN}^{d2} - r_{NN}^{d1})\,(r_{SN}^{d2} + r_{NN}^{d1}) - C_R\end{aligned}$$

Using $r_{SS}^{d2} - r_{NS}^{d1} = \frac{3\,(\mu^d\,\Delta_\tau + \Delta_c + t)}{4}$ and $r_{SN}^{d2} - r_{NN}^{d1} = \frac{3\,(\mu^d\,\Delta_\tau + \Delta_c - t)}{4}$

$$\pi_S^{d2} - \pi_N^{d1} - C_R = \frac{3\,(\mu^c\,\Delta_\tau + \Delta_c)}{4}\,(r_{SS}^{d2} + r_{NS}^{d1} + r_{SN}^{d2} + r_{NN}^{d1}) - \frac{3\,(a_N - a_S)\,t}{8} - C_R$$

Comparison of the incentives. Let us denote $DI = \pi_S^{c3} - \pi_N^{c1} - \left(\pi_S^{d2} - \pi_N^{d1}\right)$

$$\begin{aligned}DI =& \frac{3\,\Delta_c}{4}\,(r_N^{c1} + r_S^{c3})\,(\mu^c\,\Delta_\tau + \Delta_c) - \frac{3\,\Delta_\tau}{4}(r_N^{d1} + r_S^{d3})\,(\mu^d\,\Delta_\tau + \Delta_c) \\ =& \frac{3\,\Delta_c}{4}\,(r_N^{c1} + r_S^{c3} - r_N^{d1} - r_S^{d3}) + \frac{3\,\Delta_\tau}{4}(\mu^c\,(r_N^{c1} + r_S^{c2}) - \mu^d\,(r_N^{d1} + r_S^{d3})) \\ =& \frac{3\,\Delta_\mu\,(c_N\,(3\,\tau_N + \tau_S) - 2\,c_S\,(\tau_N + \tau_S))}{4} + \frac{3\,\Delta_\mu\,\Delta_\tau\,(3\,(\mu^d + \mu^c)\,\tau_N + (\mu^d + 3\,\mu^c)\,\tau_S + t - a_N - a_S)}{8}\end{aligned}$$

$\frac{\partial\, DI}{\partial\, t} = \frac{3\,\Delta_\mu\,\Delta_\tau}{8}$; $\frac{\partial\, DI}{\partial\, a_N} = \frac{\partial\, DI}{\partial\, a_S} = -\frac{3\,\Delta_\mu\,\Delta_\tau}{8}$; $\frac{\partial\, DI}{\partial\, c_N} = \frac{3\,\Delta_\mu\,(3\,\tau_N + \tau_S)}{4}$; $\frac{\partial\, DI}{\partial\, c_S} = -\frac{3\,\Delta_\mu\,(3\,\tau_N + \tau_S)}{4}$;

C. Proof of Proposition 1

We calculate global emissions for each of the four cases and compare them:

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

$E^1 - E^3 > 0$ and $E^2 - E^4 > 0$ if and only if $2\,\mu^d - 3\,\mu^c > 0$.

D. PROOF OF PROPOSITION 2

We compare prices according to the various cases:

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

E. PROOF OF PROPOSITION 3

$r_N^{c1} - r_N^{c2} = \frac{\mu^d\,\Delta_\tau + \Delta_c}{2} > 0$ implies that $\mu^c\,r_N^{c1} + \mu^d\,r_N^{d1} - \mu^c\,r_N^{c2} > 0$. Thus, the tax revenue collected in the North is lower when a dirty firm relocates.
$r_N^{d1} - r_N^{d3} = \frac{\mu^c\,\Delta_\tau + \Delta_c}{2} > 0$ implies that $\mu^c\,r_N^{c1} + \mu^d\,r_N^{d1} - \mu^d\,r_N^{d3} > 0$. Thus, the tax revenue collected in the North is lower when a clean firm relocates.
$\mu^c\,r_N^{d2} - \mu^d\,r_N^{d3} = \frac{\Delta_\mu\,(6\,\tau_N\,(\mu^d+\mu^c) - 2\,\mu^d\,\tau_S + t + 6\,c_N - 4\,c_S - a_N - a_S)}{4}$.
$\frac{\partial\left(\mu^c\,r_N^{d2} - \mu^d\,r_N^{d3}\right)}{\partial\,t} = \frac{\Delta_\mu}{4}$; $\frac{\partial\left(\mu^c\,r_N^{d2} - \mu^d\,r_N^{d3}\right)}{\partial\,c_N} = \frac{3\,\Delta_\mu}{2}$; $\frac{\partial\left(\mu^c\,r_N^{d2} - \mu^d\,r_N^{d3}\right)}{\partial\,c_S} = -\Delta_\mu$;
$\frac{\partial\left(\mu^c\,r_N^{d2} - \mu^d\,r_N^{d3}\right)}{\partial\,a_N} = \frac{\partial\left(\mu^c\,r_N^{d2} - \mu^d\,r_N^{d3}\right)}{\partial\,a_S} = -\frac{\Delta_\mu}{4}$; $\frac{\partial\left(\mu^c\,r_N^{d2} - \mu^d\,r_N^{d3}\right)}{\partial\,\tau_N} = \frac{3\,\Delta_\mu\,(\mu^d+\mu^c)}{2}$; $\frac{\partial\left(\mu^c\,r_N^{d2} - \mu^d\,r_N^{d3}\right)}{\partial\,\tau_S} = -\frac{\mu^d\,\Delta_\mu}{2}$

F. PROOF OF PROPOSITION 4

We compare $\pi_N^1 = \pi_N^{c1} + \pi_N^{d1} = {r_{NN}^{c1}}^2 + {r_{NS}^{c1}}^2 + {r_{NN}^{d1}}^2 + {r_{NS}^{d1}}^2$ to $\pi_N^2 = {r_{NN}^{c2}}^2 + {r_{NS}^{c2}}^2$.
Let us focus on the profit variation of the remaining firm:

$$\pi_N^{c1} - \pi_N^{c2} = {r_{NN}^{c1}}^2 - {r_{NN}^{c2}}^2 + {r_{NS}^{c1}}^2 - {r_{NS}^{c2}}^2 = \left(r_{NN}^{c1} - r_{NN}^{c2}\right)\,\left(r_{NN}^{c1} + r_{NN}^{c2}\right) + \left(r_{NS}^{c1} - r_{NS}^{c2}\right)\,\left(r_{NS}^{c1} + r_{NS}^{c2}\right)$$

Using, $r_{NN}^{c1} - r_{NN}^{c2} = \frac{\mu^d \Delta_\tau + \Delta_c - t}{4}$ and $r_{NS}^{c1} - r_{NS}^{c2} = \frac{\mu^d \Delta_\tau + \Delta_c + t}{4}$, we obtain:

$$\pi_N^{c1} - \pi_N^{c2} = \frac{\mu^d \Delta_\tau + \Delta_c}{4} \left(r_{NN}^{c1} + r_{NN}^{c2} + r_{NS}^{c1} + r_{NS}^{c2}\right) + \frac{t}{4} \left(r_{NS}^{c1} + r_{NS}^{c2} - r_{NN}^{c1} - r_{NN}^{c2}\right)$$

$r_{NS}^{c1} + r_{NS}^{c2} - r_{NN}^{c1} - r_{NN}^{c2} = \frac{a_S - a_N - 4\,t}{2}$

We compare $\pi_N^1 = \pi_N^{c1} + \pi_N^{d1} = {r_{NN}^{c1}}^2 + {r_{NS}^{c1}}^2 + {r_{NN}^{d1}}^2 + {r_{NS}^{d1}}^2$ to $\pi_N^3 = {r_{NN}^{d3}}^2 + {r_{NS}^{d3}}^2$.
Let us focus on the profit variation of the remaining firm:

$$\pi_N^{d1} - \pi_N^{d_2} = {r_{NN}^{d1}}^2 - {r_{NN}^{d3}}^2 + {r_{NS}^{d1}}^2 - {r_{NS}^{d3}}^2 = \left(r_{NN}^{d1} - r_{NN}^{d3}\right) \left(r_{NN}^{d1} + r_{NN}^{d3}\right) + \left(r_{NS}^{d1} - r_{NS}^{d3}\right) \left(r_{NS}^{d1} + r_{NS}^{d3}\right)$$

Using, $r_{NN}^{d1} - r_{NN}^{d3} = \frac{\mu^c \Delta_\tau + \Delta_c - t}{4}$ and $r_{NS}^{d1} - r_{NS}^{d3} = \frac{\mu^c \Delta_\tau + \Delta_c + t}{4}$, we obtain:

$$\pi_N^{d1} - \pi_N^{d3} = \frac{\mu^c \Delta_\tau + \Delta_c}{4} \left(r_{NN}^{d1} + r_{NN}^{d3} + r_{NS}^{d1} + r_{NS}^{d3}\right) + \frac{t}{4} \left(r_{NS}^{d1} + r_{NS}^{d3} - r_{NN}^{d1} - r_{NN}^{d3}\right)$$

$r_{NS}^{d1} + r_{NS}^{d3} - r_{NN}^{d1} - r_{NN}^{d3} = \frac{a_S - a_N - 4\,t}{2}$

We now compare the northern profit in cases 2 and 3.
$\pi_N^{c2} = {r_{NN}^{c2}}^2 + {r_{NS}^{c2}}^2 > \pi_N^{d3} = {r_{NN}^{d3}}^2 + {r_{NS}^{d3}}^2$ from $r_{NN}^{c2} - r_{NN}^{d3} = r_{NS}^{c2} - r_{NS}^{d3} = \frac{\Delta_\mu\,(3\,\tau_N + \tau_S)}{4}$

G. PROOF OF PROPOSITION 5

$$\begin{aligned} W_N^2 - W_N^3 = &\frac{\Delta_\mu\,\left(\tau_N\,\left(11\,\left(\mu^d + \mu^c\right)\,\tau_N + 6\,\mu^d\,\tau_S - 8\,t\right) - 16\,\delta_N\,\left(2\,\mu^d + 3\,\mu^c\right)\,\Delta_\tau\right)}{32} \\ &+ \frac{\Delta_\mu\,\left(5\,\left(3\,\mu^d + \mu^c\right)\,{\tau_S}^2 + 4\,c_S\,\left(3\,\tau_N + 5\,\tau_S + 16\,\delta_N\right) - 2\,c_N\,\left(13\,\tau_N + 11\,\tau_S + 32\,\delta_N\right)\right)}{32} \\ &+ \frac{\Delta_\mu\,\left(a_N\,\left(5\,\tau_N - \tau_S\right) + 2\,a_S\,\left(\tau_N + \tau_S\right)\right)}{162} \end{aligned}$$

Let us denote the tax revenue $TR_N^2 = \mu^c\,(r_{NN}^{c2} + r_{NS}^{c2})$ and $TR_N^3 = \mu^d\,(r_{NN}^{d3} + r_{NS}^{d3})$

$$\begin{aligned} \frac{\partial\,(W_N^2 - W_N^3)}{\partial\,a_S} &= \frac{\partial\,(TR_N^2 - TR_N^3)}{\partial\,a_S} + \frac{\partial\,(\pi_N^2 - \pi_N^3)}{\partial\,a_S} \\ &= -\frac{\Delta_\mu\,\tau_N}{4} + \frac{\Delta_\mu\,\left(3\,\tau_N + \tau_S\right)}{8} = \frac{\Delta_\mu\,\left(\tau_N + \tau_S\right)}{8} > 0 \end{aligned}$$

$$\begin{aligned} \frac{\partial\,(W_N^2 - W_N^3)}{\partial\,a_N} &= \frac{\partial\,(CS_N^2 - CS_N^3)}{\partial\,a_N} + \frac{\partial\,(TR_N^2 - TR_N^3)}{\partial\,a_N} + \frac{\partial\,(\pi_N^2 - \pi_N^3)}{\partial\,a_N} \\ &= \frac{3\,\Delta_\mu\,\Delta_\tau}{16} - \frac{\Delta_\mu\,\tau_N}{4} + \frac{\Delta_\mu\,\left(3\,\tau_N + \tau_S\right)}{8} = \frac{\Delta_\mu\,\left(5\,\tau_N - \tau_S\right)}{16} > 0 \end{aligned}$$

$$\begin{aligned}\frac{\partial\,(W_N^2-W_N^3)}{\partial\,t}&=\frac{\partial\,(CS_N^2-CS_N^3)}{\partial\,t}+\frac{\partial\,(TR_N^2-TR_N^3)}{\partial\,t}+\frac{\partial\,(\pi_N^2-\pi_N^3)}{\partial\,t}\\&=-\frac{\Delta_\mu\,\Delta_\tau}{8}+\frac{\Delta_\mu\,\tau_N}{4}-\frac{\Delta_\mu\,(3\,\tau_N+\tau_S)}{8}=-\frac{\Delta_\mu\,\tau_N}{4}<0\end{aligned}$$

$$\begin{aligned}\frac{\partial\,(W_N^2-W_N^3)}{\partial\,c_N}&=\frac{\partial\,(CS_N^2-CS_N^3)}{\partial\,c_N}+\frac{\partial\,(TR_N^2-TR_N^3)}{\partial\,c_N}+\frac{\partial\,(\pi_N^2-\pi_N^3)}{\partial\,c_N}-\delta_N\,\frac{\partial\,(E^2-E_N^3)}{\partial\,c_N}\\&=-\frac{\Delta_\mu\,\Delta_\tau}{16}+\frac{3\,\Delta_\mu\,\tau_N}{2}-\frac{3\,\Delta_\mu\,(3\,\tau_N+\tau_S)}{4}-2\,\delta_N\,\Delta_\mu\\&=-\frac{3\,\Delta_\mu\,(13\,\tau_N+11\tau_S+32\,\delta_N)}{16}<0\end{aligned}$$

$$\begin{aligned}\frac{\partial\,(W_N^2-W_N^3)}{\partial\,c_S}&=\frac{\partial\,(CS_N^2-CS_N^3)}{\partial\,c_S}+\frac{\partial\,(TR_N^2-TR_N^3)}{\partial\,c_S}+\frac{\partial\,(\pi_N^2-\pi_N^3)}{\partial\,c_S}-\delta_N\,\frac{\partial\,(E^2-E_N^3)}{\partial\,c_S}\\&=-\frac{\Delta_\mu\,\Delta_\tau}{8}-\Delta_\mu\,\tau_N+\frac{\Delta_\mu\,(3\,\tau_N+\tau_S)}{2}+2\,\delta_N\,\Delta_\mu=\frac{3\,\Delta_\mu\,(3\,\tau_N+5\tau_S+16\,\delta_N)}{8}>0\end{aligned}$$

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