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Environmental policy with endogenous plant location and tradable emission permits

by

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Environmental policy with endogenous plant location and tradable emission permits

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Abstract

A game between governments that solve environmental problems through tradable emission permits is analysed. We find that emission levels are chosen according to the Pigouvian rule, while internationally mobile firms may receive free emission permits as a location incentive. The equilibrium number of free emission permits is shown to depend on the type of environmental problem (local vs. global), the effect of firm entry on abatement costs in the rest of the economy, whether emission permits are internationally tradable or not, and the existing level of profit taxes. The introduction of tradable emissions permits fundamentally changes previous results in the literature on endogenous plant location. For instance, the NIMBY (Not In My BackYard) type of environmental policy will no longer be implemented.

1 Introduction

In the wake of the Kyoto Protocol, there has been increasing attention on tradable emission permits in environmental policy making. In several countries, tradable emission permits now seem to be a preferred policy instrument for achieving emission reductions. The EU, for instance, has decided to implement a tradable emission scheme for greenhouse gases from 2005, and several other countries are following a similar route.

With the use of tradable emissions permits come two critical policy questions. The first one is how to decide on the aggregate number of permits, and the second is how to determine the initial allocation of emission permits. In the case of the Kyoto Protocol, the aggregate number of permits available for each country is defined by the emission target that is pinned down in the agreement, so most of the discussion naturally focuses on the allocation of permits. This is also the main focus of this paper.

A principal issue in the allocation of emission permits is whether the government should keep the rent associated with the emission permits, which can be achieved through auctioning of permits, or whether the government should distribute the permits to the private sector free of charge. There are obvious reasons why it may be desirable for the government to keep the rent. As has been emphasised in the literature on "double dividends", efficiency gains for the economy as a whole can be obtained by using the permit rent in order to reduce distortionary taxes. This *revenue-recycling effect* has been discussed by Oates and Schwab (1988) and Poterba (1993), among others. More recently, it has been demonstrated that due to interaction effects with pre-existing taxes, environmental policies that do not exploit the benefits of revenue-recycling may produce significantly lower welfare levels than policies that do (Goulder *et al.* (1997), Parry and Williams III (1999), Goulder *et al.* (1999)).

But there may also be reasons for giving emission permits away for free. First, since the allocation of permits is a matter of income distribution, the permit allocation could be used to improve the income distribution of society. Distributional impacts do not however seem to be a predominant concern in discussions about the allocation of emission permits. A recent study by Parry (2003) suggests that grandfathering of emission permits may actually be highly regressive. The second reason for advocating free emission permits is that countries may use free permits in order to prevent "unnecessary" closure of firms and relocation of firms to other countries. This argument has been extensively used in the debate on the design of greenhouse emission permit schemes in European countries lately. Both EU and Norway have decided that their pre-Kyoto emission trading programs for the period 2005-2008 will have free allocation of permits. This may not be very surprising, since these are "voluntary" schemes, but the European Council has also decided that at least 90 per cent of the permits will be allocated for free also in the first Kyoto period (from 2008 to 2012).

This paper analyses the game between countries that are using free emission permits as part of their environmental policies in order to influence the location of polluting firms. The location of polluting firms may be an important issue for several reasons. For instance, it may be attractive to keep firms in the home country in order to get hold of tax revenues, maintain employment, or take advantage of various spillover effects. In the case of transboundary environmental problems, there may also be environmental reasons for wanting to keep firms at home, because lax environmental standards in other countries may exacerbate the environmental problem. With local environmental problems, on the other hand, it may be attractive to have the firm move to another country in order to reduce environmental problems at home.

Previous contributions in the literature on environmental policy with endogenous plant location have focussed almost exclusively on the use of environmental taxes. Such taxes usually have the dual role of inducing emission reductions at the same time as they are used in order to influence the pattern of firm location (e.g., Markusen et al. (1995), Rauscher (1995) and Hoel (1997)). The results suggest that policy competition may induce governments to choose environmental taxes that are both lower and higher than marginal environmental costs. A "race to the bottom" in environmental taxes is a possible outcome when the costs of having the firms located at home are small relative to the benefits. This will typically be the case with global environmental problems, where the environmental costs are the same for the host country as for other countries. With local environmental problems, however, the environmental costs of the host country may be so large that they more than outweigh the benefits of having the firms located at home. As a result, we may observe a "race to the top" in environmental taxes. This is the case of NIMBY (Not In My Back Yard) policies.

It is not difficult to realise that more efficient outcomes can be achieved by combining emission taxes with an additional policy instrument that is targeted directly towards the localisation of firms. Rauscher (1995) briefly discusses the possibility for localisation subsidies which are "lump-sum" in the sense that they do not influence abatement decisions. Direct localisation subsidies are also discussed by Mæstad (2001) as a means to reduce leakage effects in the case of unilateral attempts to solve transboundary environmental problems. However, none of these contributions has analysed the game between governments that use localisation subsidies to attract firms.

In this paper, competition for firms takes place through allocation of free emission permits to firms that are located domestically. The analytical framework is a variant of the Hoel (1997) model. In its simplest version, this is a partial equilibrium model with two identical countries and one firm that pollutes the environment. There are fixed costs of production and zero transportation costs, implying that the market will be served from one plant only. The plant will be located in the country where profits are highest. Governments are assumed to be able to credibly commit to their environmental policies. The model is thus formulated as a two-stage game, where governments choose environmental taxes at the first stage, and the firm chooses its location and its level of output at the second stage.

We modify the Hoel (1997) model in several respects. First, governments use emission permits rather than an environmental tax as their policy tool. There are then two decision variables at the first stage of the game; the target emission level and the amount of free emission permits. Moreover, we allow for both local and transboundary pollution. The case of transboundary pollution is analysed both in the absence of an international environmental agreement and in the case with an international agreement facilitating international trade in permits. Another difference is that our analysis includes an additional immobile, polluting production sector.

In our model, governments want to attract the polluting firm in order to get hold of the firm's profit through the sale of emission permits (which is equivalent to the tax income argument used by Hoel). At the same time, since the firm is assumed to be owned partly by foreigners, the governments want to pay as little as possible in order to attract firms. In practice, there may be several other reasons why governments compete for firms, as discussed above. An alternative reason for minimising expenditures on localisation incentives could be that distortionary taxes are already implemented in the economy, and that the marginal cost of public funds therefore is greater than one.

We find that the introduction of tradable emission permits fundamentally changes previous results in the literature on endogenous plant location. For instance, emission levels will always be chosen according to the Pigouvian rule of equalising marginal cost of pollution with marginal costs of abatement, while internationally mobile firms may receive free emission permits as a location incentive. The equilibrium number of free emission permits is shown to depend both on the type of environmental problem (local vs. global), the effect of firm entry on abatement costs in the rest of the economy, whether emission permits are internationally tradable or not, and the existing level of profit taxes. It is also shown that even if the mobile firm is extremely polluting and the pollution is local, the NIMBY (Not In My Back Yard) type of environmental policy will never be implemented.

The paper is organised as follows. Section 2 presents the basic model. In Section 3, we show that environmental standards will always be chosen according to the Pigouvian rule. The equilibrium number of free emission permits is analysed in Sections 4 through 7 under various assumptions about the type of pollution and the institutional setting. Throughout the analysis, it is assumed that the ownership of the internationally mobile firm is symmetrically distributed between countries. Section 8 shows that this assumption does not affect any of the conclusions. Section 9 concludes.

2 The model

There are two symmetric countries. A good y is produced with the production function $y = f(e)$, where e is a production factor that causes one unit of emissions per unit used. $f(e)$ is increasing and concave in e (i.e., $f' > 0$, $f'' < 0$). The market price of e is normalised to zero. There is a fixed, plant specific production cost F. Transport costs are assumed to be zero. Hence, the market in both countries will be served from a single plant. The firm can freely choose where to locate the plant.

The demand side does not play an important role in this analysis, and in order to simplify the exposition, we postulate an infinitely elastic demand function and an output price equal to one in both markets. Hence, there is no consumer surplus in the model.

The firm must hold emission permits for each unit of emissions. q permits are allocated to the firm for free, while the remaining $e - q$ permits must be bought in a market for tradable emission permits at the price p, which the firm takes as given. The firms' maximal profit is then

$$\pi(p, q) = \max\left[0, \max_e \left[f(e) - p(e - q) - F\right]\right] \tag{1}$$

The profit maximising level of emissions is given by

$$f_e \leq p \tag{2}$$

and the usual conditions for complementary slack. Eq. (2) defines the mobile firm's demand for emission permits as a function of the permit price, $e(p)$.

Most studies of endogenous plant location assume that there are only mobile firms in the economy or that the non-mobile firms are non-polluting. Needless to say, these are not very realistic assumptions. In particular in the case of global environmental problems such as the climate problem, there are both mobile and non-mobile emission sources. In order to take this fact into account, we introduce a non-mobile polluting sector n with a constant returns to scale technology. The abatement cost function of this sector is $c(a)$, where abatement a is the difference between the unconstrained emission level and the absence of environmental policies, e_n^0, and actual emission level from the non-mobile sector, e_n (i.e., $a \equiv e_n^0 - e_n$). Firms in the n-sector do not receive any free emission permits. Minimisation of total environmental costs $pe_n + c(a)$ implies that the n-sector will abate until marginal abatement costs equal the price of permits;

$$c'(a) = p \tag{3}$$

Eq. (3) defines the n-sector's demand for emission permits as a function of the permit price, $e_n(p)$.

The market for emission permits can either take the form of an integrated, international permit market or a separate permit market in each of the two countries. In either case, the equilibrium price of permits will be determined so as to equalise permit demand with the total number of permits made available by the governments. Let E_0 (E_1) be the total number of permits in a non-host (host) country. With domestic permit markets, equilibrium permit prices in the non-host and host countries, p_0 and p_1, are thus defined implicitly by

$$E_0 = e_n(p_0) \tag{4}$$

$$E_1 = e(p_1) + e_n(p_1) \tag{5}$$

With one integrated permit market, the permit price p is given by

$$E_1 + E_0 = e(p) + 2e_n(p) \tag{6}$$

Emissions may be partly a public bad for the two countries (transboundary pollution). The parameter γ represents the degree of international pollution spillovers. $\gamma = 0$ denotes the case of pure local pollution, whereas $\gamma = 1$ is the case of a global pollution problem (i.e., pollution is a pure public bad). The welfare costs of pollution in country i are given by $D(E_i + \gamma E_j)$. Note that due to our symmetry assumptions, the equilibrium emission standard will always be the same in the two countries (i.e., $E_i = E_j$).

Assume that residents of each country own a share α of the mobile firm. Some of the profit may also go to share holders in third countries. Hence, $\alpha \leq 0.5$.

Welfare in either country is the country's share of the profit in the mobile firm, minus the welfare loss from pollution, plus government revenues from sale emission permits, minus environmental costs in the n-sector. Let $\mathbf{E}$ be the vector of emission constraints (E_0, E_1). By utilising Eqs. (4) and (5), the mobile firm's maximal profit can be written as a function of the emission constraint and the number of free permits in the host country. Welfare levels can then be written

$$\begin{aligned} W_0(\mathbf{E}, q_1) &= \alpha\pi(E_1, q_1) + p_0 E_0 - D(E_0 + \gamma E_1) - p_0 e_n(p_0) - c(a_0) \\ &= \alpha\pi(E_1, q_1) - D(E_0 + \gamma E_1) - c(a_0), \qquad (7) \\ W_1(\mathbf{E}, q_1) &= \alpha\pi(E_1, q_1) + p_1(E_1 - q_1) - D(E_1 + \gamma E_0) - p_1 e_n(p_1) - c(a_1) \\ &= \alpha\pi(E_1, q_1) + p_1(e - q_1) - D(E_1 + \gamma E_0) - c(a_1) \qquad (8) \end{aligned}$$

Welfare of host country W_1 differs from the non-host country welfare W_0 by the government revenues from the sale of emission permits to the mobile firm. In addition, the location of the mobile firm may create welfare differences through impacts on the price of emission permits.

Equilibrium emission constraints and levels of free emission permits are found as the solution to a two-stage game. At the first stage, the governments choose their emission standard E and the number of free emission permits q to be granted to a domestically located firm. At the second stage, firms choose the location that maximises their profits and also choose their output levels. The game is solved as usual by backward induction.

3 The optimal environmental standard

This section demonstrates that it is a dominating strategy to select the environmental standard according to the Pigouvian rule. In other words, competition for firms will not affect the choice of environmental standards.

A given environmental policy (E, q) in the foreign country defines a profit level $\bar{\pi}$ that must be matched by the home country in order to attract the mobile firm. Consider fist the case where it is impossible for the home country to increase its welfare by inducing the firm to locate domestically; its best reply implies that it will become a non-host. The home country's welfare is then defined by (8). It is easily seen that the number of free emission permits in the home country does not affect its welfare, simply because the potential receiver of free permits is located abroad. The optimal emission level can be found by differentiation of (8) with respect to E_0;

$$\frac{\partial W_0(\mathbf{E}, q_1)}{\partial E_0} = -D' - c'(-\frac{de_n}{dE_0}) = 0. \tag{9}$$

By utilising the fact that $de_n/dE_0 = 1$ (see Eq. (4)) it is easily seen that the optimal emission level is defined by the condition $c' = D'$, which is the familiar Pigouvian rule that marginal costs of abatement should equal the marginal environmental damage.

Consider next the case where the best reply for the home country will induce the firm to locate in the home country. In order to derive the best reply, we differentiate $W_1(\mathbf{E}, q_1)$ with respect to the policy variables, while ensuring that $\pi(E_1, q_1) \geq \bar{\pi}$. Differentiation with respect to q_1 yields

$$\frac{\partial W_1(\mathbf{E}, q_1)}{\partial q_1} = p_1(\alpha - 1) < 0. \tag{10}$$

Hence, for a given emission standard E_1, it is desirable to choose q_1 as small as possible. The reason is that giving emission permits for free will redistribute wealth towards foreign shareholders. The optimal level of q_1 will be constrained from below by the profit level that will induce the firm to leave the country, $\bar{\pi}$. The optimal q_1 is thus given by (subscripts are omitted unless strictly required)

$$\pi(E,q^*)=\bar{\pi}\Longleftrightarrow q^*=\frac{\bar{\pi}-[f(e(p(E)))-p(E)e(p(E))-F]}{p(E)}. \tag{11}$$

By utilising (11) and (2), we find that q^*will vary with the emission standard E as follows;

$$\begin{aligned}\frac{dq^*}{dE} &= \frac{1}{p^2}\left[-\left(f_e\frac{de}{dp}\frac{dp}{dE}-p\frac{de}{dp}\frac{dp}{dE}-\frac{dp}{dE}e\right)p-\frac{dp}{dE}\left[\bar{\pi}-(f(e)-p(E)e-F\right]\right]\\ &= \frac{-1}{p^2}\left[\frac{dp}{dE}ep-\frac{dp}{dE}pq^*\right] \qquad (12)\\ &= \frac{1}{p}\frac{dp}{dE}\left[e-q^*\right]\end{aligned}$$

Next, we maximise $W_1(\mathbf{E},q)$ with respect to the emission standard E, while utilising the relationship given by (12). The first order condition is

$$\frac{dW_1(E,q)}{dE}=\alpha\left(\pi_E+\pi_q\frac{dq^*}{dE}\right)+\frac{dp}{dE}(e-q)+p\left(\frac{de}{dp}\frac{dp}{dE}-\frac{dq^*}{dE}\right)-D'-c'\left(-\frac{de_n}{dp}\frac{dp}{dE}\right)=0 \tag{13}$$

By utilising the first order condition for profit maximisation ((2), (3) and (12)) and the fact that $\frac{de}{dp}\frac{dp}{dE}+\frac{de_n}{dp}\frac{dp}{dE}=1$ (see Eq. (5)), this expression can be rewritten as

$$\alpha\left(-\frac{dp}{dE}(e-q)+p\frac{1}{p}\frac{dp}{dE}\left[e-q\right]\right)+\frac{dp}{dE}(e-q)+p-p\frac{1}{p}\frac{dp}{dE}\left[e-q\right]-D'=0, \tag{14}$$

which also reduces to the familiar Pigouvian rule of equalising the marginal cost of pollution with the marginal cost of abatement

$$p=D' \tag{15}$$

Proposition 1 *When free emission permits are used in environmental policy making, it is a dominating strategy to choose the environmental standard so as to equalise the marginal costs of pollution with the marginal costs of abatement. In other words, the competition for firms takes place through the use of free emission permits and does not affect the choice of environmental standards.*

The allocation of free emission permits does not distort decisions about inputs or outputs. Hence, it is more efficient to use free emission permits than lax emission standards in order to achieve a certain pattern of firm localisation. The result resembles Rauscher's (1995) result that it is more efficient to use lump sum transfers to firms that locate in the home country than to attract firms by low environmental standards. The allocation of free emission permits is one way in which such transfers may be implemented in practice.

The use of free emission permits has large implications for the results in previous analyses of endogenous plant location in environmental economics. This literature has emphasised that environmental taxes (or standards) tend to deviate from the Pigouvian rule once endogenous plant location is taken into account.[1] If tradable permits are used as the policy instrument, however, any location incentives will be granted through the allocation of permits, thus disentangling the issue of environmental regulation from the issue of competition for firms.

Proposition 1 implies a significant simplification in the structure of the policy game at hand. Since it is a dominating strategy to choose the environmental standard according to the Pigouvian rule, the competition for firms will take place only through the choice of the number of free emission permits to be granted. We now turn to the analysis of the equilibrium level of free emission permits under various assumptions about the nature of pollution and the institutional set up.

4 Global pollution

We now want to characterise the equilibrium number of free emission permits. We start with the case of a pure global pollutant. We also assume that there is no international agreement that restricts the emission levels. Hence, each country chooses its environmental standard so that marginal abatement costs are equal to marginal costs of pollution for this country. Since neither country takes into account the environmental costs imposed on the other country, the usual under-provision of environmental quality will result.

In the case of $\gamma = 1$, the welfare functions take the following form

$$W_0(\mathbf{E}^*, q_1) = \alpha\pi(E_1^*, q_1) - D(E_0^* + E_1^*) - c(a_0), \quad (16)$$

$$W_1(\mathbf{E}^*, q_1) = \alpha\pi(E_1^*, q_1) + p_1(e - q_1) - D(E_1^* + E_0^*) - c(a_1) \quad (17)$$

[1] Oates and Schwab (1989) show that environmental policies are not distorted in a perfect world. This result is however not very robust as it is based on the assumptions that all residual profits accrue to residents of the home country and that markets are perfectly competitive.

The difference between welfare levels is

$$W_1(\mathbf{E}^*, q_1) - W_0(\mathbf{E}^*, q_1) = p_1(e - q_1) - (c(a_1) - c(a_0)) . \tag{18}$$

The sign of $W_1 - W_0$ is ambiguous. The host country gains by being able to sell some of its permits to the mobile firm; since the firm is partly owned by foreigners, selling permits to the mobile firm represents a transfer of profits to the host country. But the host country also has higher costs of abatement in the non-mobile sector ($c(a_1) > c(a_0)$). In equilibrium, both countries will choose the same aggregate emission level ($E_i = E_j$). The presence of the mobile firm must therefore imply higher abatement by the non-mobile sector in the host country. Can this cost disadvantage be large enough to make countries abstain from competing for the mobile firm? That is one of the questions that will be answered when we now turn to the analysis of the equilibrium number of free emission permits.

Assume that the mobile firm is given all emission permits for free ($q = e$). Then, the only difference between welfare levels is the cost disadvantage of the host country. Hence, $W_0 > W_1$. This is clearly not an equilibrium. By reducing the number of free emission permits, the host country can get rid of the firm and obtain higher welfare. In equilibrium, therefore, the mobile firm will receive fewer than e emission permits for free (i.e., $q^* < e$).

Assume next that the mobile firm does not receive any free emission permits ($q = 0$). Consider figure 1. In the non-host country, the non-mobile sector must abate $a_0 = e_n^0 - E$. The abatement costs $c(a_0)$ are given by the area C. In the host country, the non-mobile sector has to abate more; $a_1 = e_n^0 - (E - e(p_1))$. Abatement costs $c(a_1)$ are then the area $B + C$. To become a host country thus increases abatement costs of the non-mobile sector by the area B.

If no emission permits are given for free, the host country gets the revenue $p_1 e(p_1)$, which is the area $A + B$. Hence, if no emission permits are given for free, the welfare of the host country exceeds the welfare of the non-host country by A. It follows that $q = 0$ cannot be an equilibrium. If neither country grants any free permits, the non-host country may attract the firm and increase its welfare by offering a small positive amount of free permits.

Proposition 2 *If marginal abatement costs in the non-mobile sector are positive and increasing in the abatement level (i.e., $c' > 0$, $c'' > 0$), the equilibrium number of free emission permits will be in the interval $0 < q^* < e^*$, i.e., some but not all emission permits used by the mobile firm will be given for free.*

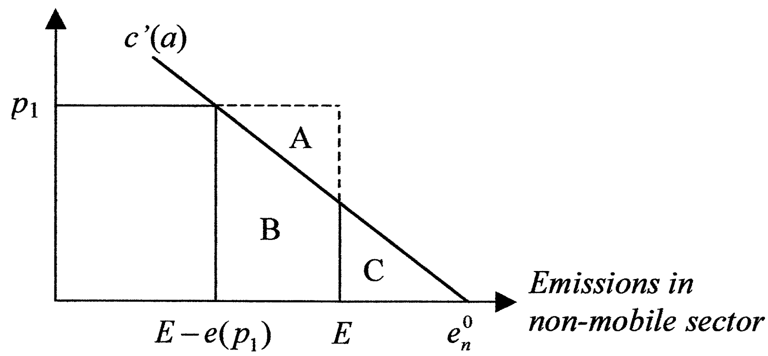

Figure 1: Abatement costs and permit revenue

Proof. It is sufficient to prove that $W_1(\mathbf{E}, 0) > W_0(\mathbf{E}, 0)$ and $W_1(\mathbf{E}, e) < W_0(\mathbf{E}, e)$. From (18) we have that

$$\begin{aligned} W_1(\mathbf{E}, e) - W_0(\mathbf{E}, e) &= c(a_0) - c(a_1) \\ &= \int_0^{a_0} c'(a)da - \int_0^{a_0+e} c'(a)da \qquad (19) \\ &= -\int_{a_0}^{a_0+e} c'(a)da < 0. \end{aligned}$$

We conclude that a positive marginal cost of abatement ($c' > 0$) is sufficient for having $W_1(\mathbf{E}, e) < W_0(\mathbf{E}, e)$ and thus $q^* < e$.

From (18) and (19) we have that

$$\begin{aligned} W_1(\mathbf{E}, 0) - W_0(\mathbf{E}, 0) &= p_1 e + c(a_0) - c(a_1) \qquad (20) \\ &= p_1 e - \int_{a_0}^{a_0+e} c'(a)da \end{aligned}$$

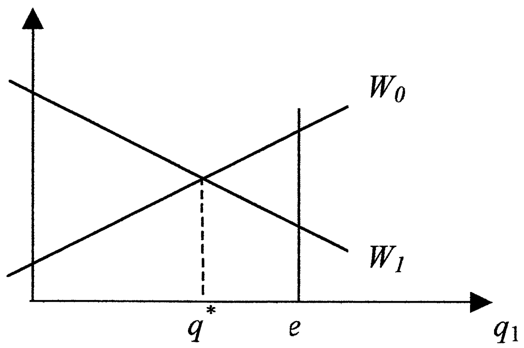

Figure 2: The equilibrium number of free emission permits

Integration by parts while utilising the fact that $p_1 = c'(a_0 + e)$ yields

$$
\begin{aligned}
W_1(\mathbf{E},0) - W_0(\mathbf{E},0) &= c'(a_0+e)e - \left[[c'(a)a]_{a_0}^{a_0+e} - \int_{a_0}^{a_0+e} ac''(a)da \right] \\
&= c'(a_0+e)e - \left[c'(a_0+e)(a_0+e) - c'(a_0)a_0 - \int_{a_0}^{a_0+e} ac''(a)da \right] \\
&= -\left[a_0 \left(c'(a_0+e) - c'(a_0) \right) - \int_{a_0}^{a_0+e} ac''(a)da \right] \qquad (21) \\
&= -a_0 \left[\int_0^{a_0+e} c''(a)da - \int_0^{a_0} c''(a)da \right] + \int_{a_0}^{a_0+e} ac''(a)da \\
&= -a_0 \int_{a_0}^{a_0+e} c''(a)da + \int_{a_0}^{a_0+e} ac''(a)da,
\end{aligned}
$$

which is positive when $c'' > 0$. Increasing marginal costs of abatement thus implies $W_1(\mathbf{E},0) > W_0(\mathbf{E},0)$ and $q^* > 0$. ∎

The equilibrium is illustrated in figure 2. From (10), (1) and (7) we have that $\partial W_1(\mathbf{E}^*, q_1)/\partial q_1 = p_1(\alpha - 1) < 0$ and $\partial W_0(\mathbf{E}^*, q_1)/\partial q_1 = p_1 > 0$. Assuming that both countries have chosen $q = q^*$, it does not pay for a host country to increase its level of free emission permits; that will only increase the transfer of profits to foreign shareholders. The host country cannot improve its welfare by reducing the number of free permits either, because that will induce the firm to locate in the other country and leave the welfare of the original host unchanged. Nor can the non-host country increase its welfare through changes in q. A reduction in q will not have any impact, since there is no firm that receives its offer of free permits. To increase the number of permits above q^* will reduce welfare, because the country will then become a host, and $W_1(\mathbf{E}^*, q) < W_0(\mathbf{E}^*, q^*)$ for $q > q^*$.

It is interesting to note that even if the mobile firm is extremely polluting and will cause a sharp increase in abatement costs in the non-mobile sector of the host country, it will still, under reasonable assumptions, be profitable to make efforts to attract the firm ($q^* > 0$). When the equilibrium price of permits equals marginal abatement costs and marginal abatement costs are increasing, there will be inframarginal rents that can be reaped through the sale of permits to the mobile firm.

Our analysis also shows that it typically will not be an equilibrium to compete away all the rent from the sale of permits to the mobile firm. Despite the fact that pollution is global, there are costs associated with having the mobile firm located at home. These costs are due to higher abatement costs in other sectors of the economy. For this reason, not all permits used by the mobile firm will be granted for free in equilibrium.

As a corollary, it is easy to show that if that there are no emissions in the non-mobile sector, the equilibrium will be to give all permits used by the mobile firm for free (i.e., $q^* = e$).

5 Local pollution

Most previous contributions in the literature on endogenous plant location consider only the case of local pollution (e.g., Hoel (1997), Markusen *et al.* (1995)). In these papers, there is typically no non-mobile sector that co-exists with the mobile firm. In this section, we reformulate our model along these more traditional lines and show that our conclusions from the previous section are robust.

With no pollution from the non-mobile sector, the mobile firm will be the only source of pollution. Assuming that pollution is at least partly local implies that $\gamma < 1$. With a purely local environmental problem (e.g., noise), γ will be zero, while other environmental problems (e.g., certain airborne pollutants) may cause certain transboundary effects although the main damage occurs locally (i.e., $0 < \gamma < 1$).

Welfare levels in this case are

$$W_0(\mathbf{E}^*, q_1) = \alpha\pi(E_1^*, q_1) - D(\gamma E_1^*), \tag{22}$$

$$W_1(\mathbf{E}^*, q_1) = \alpha\pi(E_1^*, q_1) + p_1(e - q_1) - D(E_1^*) \tag{23}$$

Proposition 3 *When pollution is partly local (i.e., $\gamma < 1$), not all emission permits used by the mobile firm will be allocated for free in equilibrium (i.e., $q^* < e$).*

Proof. Assume that both countries have chosen $q = e$. From (22) and (23) it then follows that welfare of the non-host country exceeds welfare of the host country ($W_0 > W_1$) as long as $\gamma < 1$. It then pays for the host country to reduce the number of free emission permits marginally and thus become a non-host. Hence, the equilibrium must be to choose $q < e$. ■

When pollution is partly local, there is an additional cost of having the firm located in the home country relative to a foreign location. Since no country wants to host the firm unless it is compensated for this cost, in equilibrium the host country must acquire some of the firm's profit through sale of emission permits. Hence, not all permits are granted for free. The result resembles our previous findings for the case of global pollution. While the costs of hosting the firm in that case were due to higher level of abatement in non-mobile sectors, the costs in this case come directly through higher level of local pollution.

In the literature on endogenous plant location and local pollution, one of the possible equilibria is known as the NIMBY (Not In My Backyard) case (e.g. Markusen *et al.* (1995) and Hoel (1997)). This equilibrium is characterised by a "race to the top" in environmental taxes in order to get the firm to locate abroad. The NIMBY cases that have been explored in the literature involve environmental taxes that are higher than the Pigouvian tax rate, possibly leading to equilibria without production of goods that are socially desirable to produce.

One might wonder whether similar phenomena might arise when governments use tradable emission permits as their policy tool. In this case, as we have shown, governments prefer using the permit allocation rather than the environmental standard to get rid of excessively polluting firms. Can we then get a race to the bottom in the allocation of free emission permits, i.e., giving as few permits for free as possible? In principle, the number of free emission permits could be negative, in which case firms would be required to buy permits in excess of the number of permits that corresponds to their emissions. To implement a policy with a negative number of free permits may however not be possible to implement in practice, but then the question arises whether we can revert to the case where environmental standards (or taxes) are raised above the Pigouvian levels in order to get rid of firms?

Consider first the question of whether a race to the bottom in the number of free emission permits can be an equilibrium, where a race to the bottom will be defined as $q < 0$. A necessary condition for having a race to the bottom would be that the welfare of the non-host country exceeds the welfare of the host country when $q = 0$. i.e., $W_0(\mathbf{E}^*, 0) > W_1(\mathbf{E}^*, 0)$. Assume that pollution is purely local ($\gamma = 0$). From (22) and (23) we then have that a race to the bottom in q requires that

$$\alpha\pi(E_1^*, 0) > \alpha\pi(E_1^*, 0) + p_1 e - D(E_1^*) \tag{24}$$

or

$$p_1 e - D(E_1^*) < 0 \tag{25}$$

which is to say that the environmental costs from having the firm located domestically must exceed the total permit rent. The following result can now be obtained:

Proposition 4 *If marginal environmental costs are increasing in the emission level, the equilibrium level of free emission permits will always be positive, even with pure local pollution.*

Proof. By utilising (15), (25) can be rewritten as

$$D'e - \int_0^{E^*} D'(e)de < 0 \tag{26}$$

Integration by parts yields

$$D'e - \left([D'(e)e]_0^{E^*} - \int_0^{E^*} eD''(e)de \right) < 0 \tag{27}$$

$$\int_0^{E^*} eD''(e)de < 0 \tag{28}$$

Eq. (19) is violated as long as $D'' > 0$. Hence, with increasing marginal costs of pollution, $W_0(E_1^*, 0) < W_1(E_1^*, 0)$. Since $W_1(E_1^*, q_1)$ is decreasing in q_1 and $W_0(E_1^*, q_1)$ is increasing in q_1, $q > 0$ in equilibrium. ■

We have shown that when environmental standards are defined by the Pigouvian rule, governments will issue some free emission permits in order to attract the polluting firm to the home country ($q > 0$) as long as marginal environmental costs are increasing in the level of pollution. In other words, there will be no race to the bottom in the number of free emission permits. As a consequence, even if the number of free permits is constrained to be non-negative, the environmental standard will never be raised above the Pigouvian level.

The intuition is that when marginal environmental costs are increasing, the total permit rent will always exceed total environmental costs as long as the permit price is equal to the marginal cost of pollution. If the government keeps the entire permit rent (by not allocating any permits for free), welfare

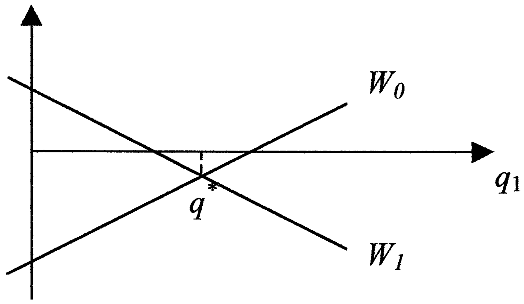

Figure 3: Equilibrium with no production

of the host country must then exceed welfare of the non-host country. In equilibrium, this excess welfare will be competed away by offering a positive number of free permits to the polluting firm.

None of these results implies that the polluting firm will actually be operating in equilibrium. The equilibrium price of emission permits may be so high (because marginal environmental costs are high), that the firm's profit will be negative even though it receives some of the emission permits for free. The situation may for instance be as depicted in figure 3.

In this case, the equilibrium welfare levels are negative for both countries. Since the non-host country's welfare with purely local pollution is $W_0(E_1, q_1) = \alpha\pi(E_1, q_1)$, this must imply that the firm's profit is negative and that the good therefore is not produced.

Hoel (1997) finds that non-production may occur even if it is socially desirable to produce the good. In our model, such socially inefficient equilibria do not arise. In equilibrium, welfare levels must be equal in the two countries, i.e., $W_1(E_1^*, q_1^*) = W_0(E_1^*, q_1^*) = \alpha\pi(E_1^*, q_1^*) - D(\gamma E_1^*)$. Thus, aggregate welfare cannot be positive unless the firm's profit is positive ($\pi(E_1^*, q_1^*) > 0$). This conclusion is however not robust. If there is consumer surplus in both countries from consumption of the good, aggregate welfare may be positive even though the firm's profit is negative. Socially inefficient equilibria may occur in this case because the governments do not take into account the positive effect on consumer welfare in the foreign country of implementing policies that induce closure of the firm.

6 Global pollution with international permit trade

In the previous sections, the permit price was allowed to differ between countries. This is obviously not a Pareto efficient solution; if there are differences in permit prices, welfare in both countries will increase through international trade in emission allowances. Such international permit trade is an important part of the Kyoto Protocol. We now investigate the implications of international permit trade for the equilibrium number of free emission permits.

We assume that the countries have signed an international environmental agreement that specifies an emission target $\bar{E}$ in both countries. Emission allowances are internationally tradable at a price p, which is defined by the equilibrium condition in the permit market (cf. Eq. (6))

$$2\bar{E} = e(p) + 2e_n(p). \tag{29}$$

Note that the number of free emission permits does not affect the equilibrium permit price. p is thus taken as given by the governments. With a given p, the localisation of the firm will not affect environmental costs in the non-mobile sector. This sector can thus be ignored. The host country earns the permit rent $p(\bar{E} - q)$, while the permit rent in the non-host country is $p\bar{E}$. Welfare levels are then

$$W_0(\bar{E}, q_1) = \alpha\pi(\bar{E}, q_1) + p\bar{E} - D(2\bar{E}) \tag{30}$$
$$W_1(\bar{E}, q_1) = \alpha\pi(\bar{E}, q_1) + p(\bar{E} - q_1) - D(2\bar{E}) \tag{31}$$

Proposition 5 *With an international environmental agreement and international permit trade, no emission permits are given for free in equilibrium.*

Proof. Assume that both countries have chosen $q = 0$. Both countries then have the same level of welfare ($W_0 = W_1$). As before, we have that $\partial W_1/\partial q_1 < 0$ (see (10)). Hence, its is clearly not profitable for the host country to increase q. For the non-host country to reduce q would have no impact on its welfare. The non-host country could attract the firm by choosing $q > 0$, but its welfare would then decline as $W_1(\bar{E}, q) < W_1(\bar{E}, 0) = W_0(\bar{E}, 0)$ for $q > 0$. By choosing $q < 0$, the host country would get rid of the firm, but its welfare would not improve. Hence, the equilibrium is $q^* = 0$. ■

International permits trade thus has a powerful impact on the equilibrium number of free emission permits. While the equilibrium number of permits might approach e in the absence of permit trade and indeed be equal to e in the absence of a non-mobile sector, no permits will be given for free once international permits trade is allowed for. International permits trade implies that non-used permits have an alternative value p. Since the mobile firm will not pay more than p for the permits, no surplus rent can be gained by attracting the mobile firm. Quite contrary, if free emission permits must be granted in order to attract the firm, becoming a host country involves a loss in welfare.

7 Profit taxes and free emission permits

In our analysis, the driving force for issuing free emission permits to mobile firms is the potential of capturing a larger share of the firm's rent from its use of the environmental resource. In practice, the profit of firms is also taxed through the ordinary tax system. In this section, we analyse how the existence of an ordinary profit tax may affect the use of free emission permits.

Consider the model with an international environmental agreement with free international trade in permits. Our previous analysis showed that in this case, no permits are given for free in equilibrium. This result does however not survive if profit taxes are implemented. Let t be an exogenous profit tax rate. Welfare levels are now

$$W_0(\bar{E}, q_1, t_1) = \alpha\pi(\bar{E}, q_1)(1 - t_1) + p\bar{E} - D(2\bar{E}) \tag{32}$$

$$W_1(\bar{E}, q_1, t_1) = \alpha\pi(\bar{E}, q_1)(1 - t_1) + t_1\pi(\bar{E}, q_1) + p(\bar{E} - q_1) - D(2\bar{E}) \tag{33}$$

It is easily seen that if the profit tax rate is positive, $q = 0$ is no longer an equilibrium, because $W_1(\bar{E}, 0, t) > W_0(\bar{E}, 0, t)$. It then pays for the non-host country to increase q slightly and thus become a host. In equilibrium, all revenue generated by the host country through profit taxes will be competed away through the allocation of free emission permits (i.e., given the tax rate t the equilibrium number of free emission permits is given implicitly by $q^* = t\pi(\bar{E}, q^*)/p$, obtained by equalising expressions (32) and (33)).

So far, we have only shown that $q > 0$ is an equilibrium for a given exogenous positive tax rate $t > 0$. We now want to show that $(q^* > 0, t^* > 0)$ may be an equilibrium in a game where the profit tax and the number of free emission permits are chosen simultaneously. In order to do so, notice first that profit taxes and free emission permits are equally efficient measures for competing for firms, because neither of the instruments affects the firm's input or output decisions (as long as after tax profits remain positive). Hence, t and q can be seen as perfect substitutes. Therefore, if it can be shown that one $(q > 0, t > 0)$ is an equilibrium, there will be an infinite number of such (q, t) equilibria.

Let q^* be the equilibrium number of free emission permits given that $t = t^* > 0$. In order to show that t^* then is an equilibrium, notice that from (32) and (33) we have that the host country welfare (non-host welfare) is monotonically increasing (decreasing) in t (for $t < 1$);

$$\frac{\partial W_0}{\partial t_1} = -\alpha\pi < 0, \tag{34}$$

$$\frac{\partial W_1}{\partial t_1} = (1-\alpha)\,\pi > 0. \tag{35}$$

A higher tax rate implies that more of the firm's profit accrues to the host country and correspondingly less goes to the non-host. We can now prove the following proposition.

Proposition 6 *If the host country uses profit taxes ($t > 0$), a positive number of free emission permits will be issued in equilibrium ($q > 0$), even though permits are traded internationally at a given price.*

Proof. Welfare levels are equal in the host and non-host countries at (q^*, t^*) because this is required in order for q^* to be an equilibrium (i.e., $W_0(\bar{E}, q^*, t^*) = W_1(\bar{E}, q^*, t^*)$). For the non-host country to reduce its tax rate in order to attract the firm would then reduce welfare, since $W_0(\bar{E}, q^*, t^*) > W_1(\bar{E}, q^*, t)$ for $t < t^*$. To increase the tax rate in the non-host country would leave the non-host country welfare unchanged. For the host country, a reduction in the tax rate is clearly welfare reducing. To increase the tax rate will also reduce welfare, because the firm will then change location, and $W_0(\bar{E}, q^*, t) < W_1(\bar{E}, q^*, t^*)$ for $t > t^*$. This proves that $(q^* > 0, t^* > 0)$ is an equilibrium in this game. ∎

When profit taxes are implemented, the host country captures rent from the mobile firm. This rent will be competed away in equilibrium. Hence, the equilibrium number of free emission permits will be positive.

8 Asymmetric ownership

The analysis above assumes that both countries own an equal share of the mobile firm. What would be the effect of asymmetric ownership, i.e., one country owning a larger share of the firm than the other? Asymmetric ownership complicates the analysis, because it is not enough to distinguish between a host and a non-host country, but we also need to keep track of which country is which.

Let W_1^i and W_0^i denote welfare of country i when it is a host and a non-host, respectively. We first ask whether an increase in country i's ownership of the firm changes its best response to a given q^j set by country j. We know that if $W_1^i(q^j) > W_0^i(q^j)$, then it will be a best reply to set $q^i > q^j$ in order to attract the firm. Similarly, if $W_1^i(q^j) < W_0^i(q^j)$, the best response would be to set $q^i < q^j$. Hence, in order to check whether a change in ownership structure changes the best reply, it suffices to check whether a change in α will change the level of q that satisfies $W_1^i(q) = W_0^i(q)$.

In all cases considered, welfare levels for country i can be written on the following general form

$$W_0^i(q) = \alpha\pi(q)(1-t) + A, \tag{36}$$
$$W_1^i(q) = \alpha\pi(q)(1-t) + t\pi(q) - pq + B, \tag{37}$$

where A and B represent factors that are independent of q. It is clear that changes in α will change both the levels and the slopes of W_0^i and W_1^i. Nevertheless, it is easily seen that changes in α will not affect the level of q that satisfies $W_1^i(q) = W_0^i(q)$. Hence, country i's best reply to q does not change if the ownership structure changes. The same is of course true for country j. This proves that the equilibrium levels of free emission permits derived in the previous sections are robust to changes in the ownership structure.

Proposition 7 *Asymmetric ownership of the mobile firm does not affect any of the previous conclusions.*

9 Concluding remarks

This paper has shown that the use of tradable emission permits in environmental policy making may radically change the conclusions in previous analysis of environmental policy with endogenous plant location. With tradable permits there are essentially two policy instruments; the emission standard and the initial allocation of permits. Since permit allocation is a more efficient instrument for affecting the pattern of firm location than the emission standard, the emission standard will no longer be affected by the fact that firms are internationally mobile. Environmental standards will then be chosen according to the Pigouvian rule. Hence, there will be neither a race to the bottom nor a race to the top in environmental standards, as are possible equilibria when only an emission tax is used.

Internationally mobile firms can be attracted to the home country by issuing free emission permits. The equilibrium number of free emission permits is generally found to be in the interval between zero and the actual emission level of the mobile firm. When there is local pollution or when the entry of a mobile firm implies that abatement will increase in the non-mobile sector of the economy, not all permits used by the mobile firm will be issued for free, because the host must be compensated for the costs of hosting the mobile firm.

When emission permits can be traded internationally at a given price, no permits will be granted for free, because the environmental resource rent then can be obtained by the governments independently of where the mobile firm is located. However, governments have implemented profit taxes, a positive number of free emission permits will be issued in this case as well.

Finally, we show that even if the mobile firm is extremely polluting and polluting is local, the equilibrium entails a non-negative number of free emission permits as long as the marginal welfare costs of pollution increases with the emission level. Under this (weak) assumption, there will always be inframarginal rents that can be captured by hosting the polluting firm. Thus, countries will make efforts to become the host, even for extremely polluting firms. The NIMBY story thus disappears when tradable emission permits are used as the policy tool.

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