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Domestic Environmental Policy under Asymmetric Information: The role of foreign ownership, outside options and market power

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DOMESTIC ENVIRONMENTAL POLICY UNDER ASYMMETRIC INFORMATION:

The role of foreign ownership, outside options and market power[1]

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Abstract:
We analyse environmental policy under asymmetric information in a context where a home-polluting firm, selling its final output solely in a foreign market with some market power, has an option to bypass domestic regulation through setting up new plants in a jurisdiction offering lenient environmental standards. The hidden characteristics are emission intensity and outside option, assumed perfectly correlated, so that the firm has a type-dependent reservation utility. There is mixed ownership to the firm; a fraction is owned by foreigners whose welfare does not enter the home government's objective function. The home government has a limited set of policy instruments; in fact only net emissions can be taxed. The familiar trade-off between efficiency and rent extraction will involve over-pollution, with (possibly) a subset of the most emission-intensive firm types being induced to relocate. This effect is reinforced by increased foreign ownership, as the cost of leaving rent then increases. (Ownership has no real impact under complete information.) Weaker market power, due to increased competition at the world market, will work in the same direction, but now there is a counteracting effect due to a lower outside option.

Keywords: Asymmetric information, environmental regulation, globalisation
JEL classification: D62, D82, H23, L51, Q28

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1. Introduction

A challenge facing most national governments is how to cope with substantial changes in the external economic environment, especially those phenomena classified as "globalisation". Lower trade-barriers and more global competition involve new constraints to which almost any country has to adapt. National tax systems can no longer be designed without taking into account the possible consequences for the re-localisation of firms and mobile factors of production. Inter-jurisdictional tax competition takes place, as a way of attracting foreign firms to locate within own jurisdiction or to prevent domestic firms to move abroad. Lenient environmental standards may serve the same purpose, as a way of improving the working conditions of firms operating within its jurisdiction.

The issue of international firm mobility will be analysed in the present paper. We concentrate on a situation where a home government is to design its environmental policy when facing a privately informed home-polluting firm (representing the whole industry) that threatens to bypass domestic regulation by setting up new plants in jurisdictions offering lax environmental standards. Rather than analysing the policy game as a non-cooperative complete information game between governments (as done e.g. in Markusen et al. (1995), Rauscher (1995), Hoel (1997) or Dijkstra (2003), we'll emphasise the role of asymmetric information between the government and the industry, when external environmental policy is taken as given. We bring together two approaches - one that focuses merely on asymmetric information and environmental policy design (see e.g. Baron (1985), Spulber (1988), Laffont (1994) and Lewis (1996)), and one emphasising the impact of domestic environmental policy on the delocation of firms, when foreign environmental standards are taken as given, as analysed e.g. by Markusen et al. (1993), and Motta and Thisse (1994). The home-polluting industry has private information about abatement technology *and* outside option, which itself is affected by external environmental standards and global competition. The main question we try to answer is how domestic environmental policy design is affected by foreign environmental dumping and also what firm types that should be induced to relocate. (An important feature of the model is that some firm types should be induced to shut down their domestic operations, despite the public concern about job destruction and "loss in competitiveness". Rather than responding to domestic firms' threats of moving abroad, by offering lenient environmental standards at a too high social cost, the home government should simply wish the firms "bon voyage".)

In section 2 we present the theoretical framework that will enable us to discuss how to cope with external environmental dumping, when a home-operating polluting firm has private information about emission technology as well as the value of the outside option. To make things simple, we consider regulation in one period only, and to get rid of a number of technical problems related to multidimensional type space, as analysed by Armstrong (1999), and by Armstrong and Rochet (1999), we assume that the value of the outside option is perfectly correlated with emission intensity. An implication is then that we end up with a standard regulation problem with a type-dependent participation constraint that does not create any analytical problems. (See Jullien (2000) for a detailed analysis of how to cope with type-dependent participation constraints in general.) The model consists of a domestic government, with a welfare function as given by the sum of domestic taxpayers' surplus and the share of the firm's rent accruing to domestic owners. (To see the role of ownership on the optimal regulation, we let a fraction of the firm be owned by foreigners whose welfare does not enter the home government's objective function.) The objective is to maximise expected welfare, subject to the relevant incentive constraints, but because we assume that the firm's output cannot be verified, only net emissions can be taxed. The firm generates revenue only from export, but produces a social cost through (local) environmental damage, with a technology that is private information. (See Calzolari and Scarpa (2001) for a closely related problem. Their focus is on domestic regulation of a multinational enterprise, with foreign owners, earning profits both in a foreign market and in the home market, when there are economies or diseconomies of scope.)

In section 3 we show that if information is complete, the output sold abroad and net emissions at home should obey ordinary efficiency conditions, despite the fact that the government has access only to a limited set of policy instruments. This imperfection can, however, be circumvented by imposing a two-part Pigovian tax, with the variable part relating the tax to net emissions, while the fixed part, serving the role as "an entrance fee", is fixed so as to give the firm a rent exactly equal to its outside option. Under complete information we assume that no firm type should be induced to relocate. This conclusion does not necessarily carry over to incomplete information. Because of private information, the firm will be able to capture a rent. The social cost of leaving rent is positive, and will be higher the more of the firm is owned by foreigners. To reduce expected rent, the government should allow the firm to have higher net emissions than under complete information, as shown in section 4. The reason is two-fold: First, higher net emissions will serve as a profit-shifting instrument as more output will be produced and higher revenue can be extracted in the foreign market. (The strength of this effect is related to the firm's market power at the world market.) Secondly, when inducing the firm to generate higher net emissions, the firm will undertake less pollution abatement. With private information, the firm will in this model have an incentive to overstate its emission intensity so as to capture a rent. To mitigate this incentive, highly emission-intensive firm types should be encouraged to undertake less pollution abatement. This type of distortion will make it less profitable for types with low emission intensity to take advantage of their superior emission technology. (This feature of the model is the familiar trade-off between efficiency and rent extraction found in the new economics of regulation; see Baron and Myerson (1982), and Laffont and Tirole (1993).) Welfare will under complete information be declining in emission intensity. Because of distortions and the necessity of leaving costly rent to the firm, type-contingent (ex post) welfare will fall below what could be achieved under complete information. Hence, because we assume that outside option will be increasing in emission intensity, it might be socially desirable to cut off a subset of types with high emission intensity. One effect of asymmetric information, along with inter-jurisdictional differences in policy design, might therefore be higher international firm mobility. In section 5, we show that the distortions in net emissions as compared to first best will also be affected by ownership structure and market power. Higher foreign ownership makes rent extraction more important, implying that net emissions will be increased even further from those firm types that do not relocate, while the mass of firm types that should leave will increase as well. The impact on expected environmental damage, relative to complete information, is therefore ambiguous. A higher competitive pressure in the foreign market makes rent extraction more important, calling again for higher net emissions and a higher proportion of the firm types being induced to relocate. However, a higher competitive pressure abroad will also reduce the value of the outside option, which calls for reducing the upward distortions in net emissions, because inducing truth-telling now becomes less costly. Again the impact on expected environmental damage is ambiguous. In section 6 we show how the second-best emission path can be implemented by a modified two-part emission tax. Section 7 concludes. (Some technical aspects of the model are outlined in the Appendix.)

2. The Model

We want to analyse domestic environmental policy design when the regulated firm has an option to relocate. We can think of a global arena where some external government chooses to impose a rather lenient environmental standard as compared to the home government. The firm located within the home government's jurisdiction has private information both about emission technology and the value of some outside option. The presence of private information will enable the firm to capture an informational rent, of which only a fraction will enter the home government's objective function because of foreign owners. (The domestic firm can be seen as member of a multinational enterprise.) To have a non-trivial problem, we assume that the home government has only a limited number of available instruments. First, lump-sum taxation is ruled out, but in addition, we assume that neither output nor profits can be taxed. (The latter part of this assumption might be justified by international tax competition itself, or by some political imperfection.) The firm sells the entire output in a foreign market where it has some market power. Jointly with the final output, the firm produces a "bad" (or pollution) that is "consumed" solely by domestic citizens. As is well known, to correct for these externalities, the domestic government should design a tax on emissions so as to get the firm to undertake necessary pollution abatement (which cannot be verified). The tax should serve three purposes: correcting for external costs, extracting costly rent from the firm, and extract revenue from foreign buyers. Therefore the design of the tax scheme seems to become rather intricate.

2.1 The firm's technology and its environment

The firm's objective is to maximise rent, denoted U, which is both location- and type-dependent. Gross profits from selling an amount of y units of the output at the world market is given by a twice continuously differentiable and strictly concave function $\pi(y)$, with a unique (global) maximum for $\tilde{y} > 0$. We assume $\pi(0) = 0$, and that $\pi'(0)$ is sufficiently high, properties that will be satisfied if we let foreign demand be of the constant elasticity-type and with a homothetic production technology with decreasing returns to scale. Foreign (inverse) demand facing the firm is $e(y) = Ay^{-\frac{1}{\varepsilon}}$, with *A* being a positive constant and demand is elastic by assumption, with $\varepsilon > 1$, for any $y \in [0, \tilde{y}]$. The parameter ε is the absolute value of the elasticity of demand. Given the underlying production technology, the cost function can be expressed as $y^{\beta} \cdot \phi(w)$, where β is a constant greater than one (due to decreasing returns to scale), with *w* as a vector of fixed input prices. For ease of exposition, we normalise so that $\phi(w) \equiv 1$. Given these assumptions, we have that the unregulated profit-maximising output level is given by

$$\text{(1)} \qquad \tilde{y} = \arg\max_{y} \left\{ Ay^{1-\frac{1}{\varepsilon}} - y^{\beta} \right\} = \left[\frac{(\varepsilon - 1)A}{\beta\varepsilon} \right]^{\frac{\varepsilon}{1+\varepsilon(\beta-1)}}$$

For later use, it is convenient to have some measure of how marginal gross profits vary with output. Define therefore the absolute value of the elasticity of the marginal gross profits with respect to output; $\eta(y) := -El\,\pi'(y) : y$, which is positive. We then have:

Lemma 1

Given our assumptions $\eta(y) = \dfrac{1 + \varepsilon(\beta - 1)\Lambda(y)}{1 - \Lambda(y)} > 1$ *for* $y \in [0, \tilde{y})$, *where*

$$\text{(2)} \qquad \Lambda(y) := \frac{\beta}{A(1 - \frac{1}{\varepsilon})} \cdot y^{\beta - 1 + \frac{1}{\varepsilon}} \in [0,\ 1)$$

(It is easy to verify that for any $y \in [0, \tilde{y})$, we have $\Lambda(y) \in [0,1) \Leftrightarrow \pi'(y) > 0$.) When doing comparative static analysis later, we define weaker market power or higher competitive pressure abroad as a downward shift in A, which will lower $\tilde{y}$, while both $\Lambda(y)$ and $\eta(y)$ will increase.

The firm has a fixed-coefficient technology relating output and the amount of primary discharges (gross emissions), given by θy, where θ is a technology parameter, which is a measure of the firm's emission intensity. The higher θ is, the more emission-intensive (or dirty) is the technology. This parameter is known only to the firm and indicates its type. It is common knowledge that $\theta \in [\underline{\theta}, \overline{\theta}] := \Theta$, and according to the home government's beliefs, θ is distributed according to the strictly increasing and twice continuously differentiable cumulative distribution function $F(\theta)$, with positive density *f* on Θ. The distribution obeys the "monotone hazard rate property"; i.e. $\frac{d}{d\theta}\frac{F(\theta)}{f(\theta)} \geq 0$.

Although we assume a fixed type-dependent relationship between output and primary discharges, the relationship between output and net emissions can be modified through costly and unverifiable pollution abatement. For a level of net emissions, *x*, pollution abatement is simply given by $\theta y - x$, with a cost at the firm level as given by $v(\theta y - x)$. We assume that $v(\cdot)$ is thrice continuously differentiable, strictly increasing and strictly convex for any positive level of abatement, with $v(0) = v'(0) = 0$. (We also assume that $v''' \geq 0$.) The social damage or environmental cost caused by net emissions is given by a twice continuously differentiable, strictly increasing and strictly convex damage function, $D(x)$, with $D(0) = D'(0) = 0$.

2.2 The options to the firm

Consider first the case where the firm chooses to relocate. If moving its operations abroad, the firm has to incur a set-up cost or a cost of relocation, $c(\theta)$, which is assumed to be twice continuously differentiable and (strictly) decreasing. (In addition we assume $c(\theta)$ to be concave as well, which is stronger than necessary for having a connected participation set.) We can justify the type-dependent set-up cost by assuming that the emission intensity will vary with the technique (or vintage of installed capital equipment). A plant using an "old" technique is less costly to move than a plant with a more modern technique. As mentioned earlier, an important feature of this specification is that the firm's outside option or reservation utility, $R(\tilde{y},\theta)$, then becomes type-dependent, and will be increasing in θ. If choosing to relocate, the firm will have a rent as given by

$$(3) \qquad U^{out} = max_{y} \{\pi(y) - c(\theta)\} = \pi(\tilde{y}) - c(\theta) := R(\tilde{y},\theta)$$

If relocation takes place, there is a social gain, as local environmental damage will vanish altogether, but there is a loss as well, as no tax revenue will be collected. We therefore have that taxpayers' surplus in this case will be $CS^{out} = 0$.

Suppose next that the firm decides to stick to its original location. If domestic intervention requires the firm to generate net emissions x, while paying some an amount of emission tax *T*, and the firm has full discretion as to how much to be produced and sold abroad, its rent will be given by

$$(4) \qquad U^{in} = \pi(Y(\theta,x)) - v(\theta Y(\theta,x) - x) - T$$

with the non-verifiable output being determined according to:

$$(5) \qquad Y(\theta,x) = arg\,max_{\,y} \left\{ \pi(y) - v(\theta y - x) - T \,\middle|\, U^{in} \geq R(\tilde{y},\theta) \right\}$$

Given our assumptions, the firm's decision rule $Y(\theta,x)$, which is common knowledge, will obey the properties given in Lemma 2:

Lemma 2

As long as the firm prefers domestic location, output chosen by the firm will obey the decision rule, $Y(\theta,x)$*, with properties as given by*

(i) $\quad Y(\theta,x) \in [0,\tilde{y}] \;\; \forall \theta \in \Theta, \; \forall x \in [0, \theta\tilde{y}]$

(ii) $\quad \dfrac{\partial Y}{\partial x} := Y_x = \dfrac{-\theta v''}{\pi'' - \theta^2 v''} > 0, \quad \dfrac{\partial Y}{\partial \theta} := Y_\theta = \dfrac{v' + \theta Y v''}{\pi'' - \theta^2 v''} < 0$

(iii) $\quad Y_x \cdot (v' + \theta Y v'') = -\theta v'' Y_\theta, \quad \theta Y_x - 1 = -\dfrac{\pi''}{\pi'' - \theta^2 v''} < 0$

(iv) $\quad Y(\theta,x) + \theta Y_\theta(\theta,x) = \dfrac{\pi' \cdot (1-\eta)}{\pi'' - \theta^2 v''} > 0 \quad for\; Y(\theta,x) \in [0, \tilde{y})$

This lemma states, first of all, that in any relevant policy regime, output is bounded below the unregulated output level $\tilde{y}$. Secondly, for a given emission intensity (θ), output is increasing in net emissions. (A less restrictive emission standard, or a higher

x, will lower the marginal cost of abatement.) Third, for some given net emission, output is declining in the firm's emission intensity. For any type of the firm, pollution abatement is declining in emission requirement. At last, the amount of primary discharges will for any fixed x, be increasing in emission intensity.

2.3 The government's options

When the firm is complying with domestic regulation, the taxpayers' surplus will consist of the social value of the tax revenue minus the social cost due to local pollution, $D(x)$, as given by

$$(6) \qquad CS^{in} = (1+m)T - D(x)$$

Lump-sum taxation is ruled out by assumption; hence, any tax revenue collected from the firm has a social value $(1+m)T$, where m is the (exogenous) marginal cost of public funds.

The home government's objective function consists of the sum of the taxpayers' surplus (*CS*) and the share of rent accruing to domestic citizens. Suppose that a fraction, $\alpha \in [0,1]$, of the firm is owned by domestic citizens. (The ownership structure is taken as given.) The welfare function is therefore

$$(7) \qquad W = CS + \alpha U$$

The objective of the home government is to maximise the expected value of W, subject to relevant constraints.

3. The Benchmark Solution (First Best)

Consider first the optimal solution under complete information. The firm will always go for the option with the higher rent; i.e. given some policy regime, it will choose location according to the criterion $max\{U^{in}, R(\tilde{y},\theta)\}$. Denote maximal welfare under complete information by W^*, determined as

$$(8) \qquad W^* = Max\left\{Max_{x,U^{in}}[S(\theta,x)-\gamma U^{in} \,\middle|\, U^{in} \geq R(\tilde{y},\theta)]\,,\alpha R(\tilde{y},\theta)\right\}$$

where $S(\theta,x):=(1+m)\cdot\left[\pi(Y(\theta,x))-v(\theta Y(\theta,x)-x)\right]-D(x)$ is the gross social surplus generated with a pollution level *x*. The parameter $\gamma:=1+m-\alpha$ can be seen as a tax-adjusted welfare weight put on the firm's rent, so that a unit increase in rent will have a higher social cost the lower is α. (Note also that for any emission standard (*x*), there are no incentive issues with regard to output, because firm's choice of output is fully compatible with the objective of the home government.)

Assume that under complete information there exist emission levels so that any type of the firm should be induced to stick to its original location. Call this assumption ***F****ull* ***P****articipation under* ***C****omplete* ***I****nformation* (*FPCI*). As long as $\gamma > 0$, only the participation constraint must be honoured; hence leaving rent beyond the outside opportunity is a pure waste.

(FPCI): *For any* $\theta \in \Theta$ *and for some x > 0, we have*

$$S(\theta,x)-\gamma R(\tilde{y},\theta) > \alpha R(\tilde{y},\theta) \Leftrightarrow c(\theta)-v(\theta Y(\theta,x)-x)-\frac{D(x)}{1+m} > \pi(\tilde{y})-\pi(Y(\theta,x))$$

i.e., that the increased private gross profits from bypassing domestic regulation is insufficient to compensate for the cost savings from relocation.

Under complete information, we then have that net emissions will maximise social surplus $S(\theta,x)$. Hence, it should not come as a surprise that we have the following result:

Proposition 1

First-best optimal allocation is characterised by a level of net emissions, rent, output and social welfare, all type-contingent, so that:

$$(9\text{-}i) \qquad (1+m)v'(\theta Y(\theta,x^*)-x^*) = D'(x^*) \qquad \textit{(Cost efficiency)}$$

$$(9\text{-}ii) \qquad U^{in} = R(\tilde{y},\theta) \qquad \textit{(Rent extraction)}$$

$$(9\text{-}iii)\quad \pi'(Y(\theta,x^*)) - \theta v'(\theta Y(\theta,x^*) - x^*) = 0 \qquad \textit{(Revenue extraction)}$$

$$(9\text{-}iv)\quad W^*(\theta) = S(\theta,x^*(\theta)) - \gamma R(\tilde{y},\theta) \qquad \textit{(Welfare)}$$

Net emissions should obey cost efficiency, saying that social marginal damage should be equal to the social value of marginal cost of abatement, conditional on the output level, $Y(\theta,x^*) < \tilde{y}$, that maximises the firm's net profit from selling abroad given x^*; cf. (*9 i,iii*). As mentioned above, rent extraction is accomplished by offering a rent to the firm matching its outside option, whereas welfare is the associated social surplus minus the tax-adjusted value of rent accruing to domestic owners.
From this proposition we can make the following observations:

Observation 1: Maximal social welfare $W^*(\theta)$ is declining in θ, as seen from

$$(10)\qquad \frac{\partial W^*(\theta)}{\partial \theta} = -(1+m)Y(\theta,x^*(\theta))\cdot v'(\theta Y(\theta,x^*(\theta)) - x^*(\theta)) + \gamma c'(\theta) < 0$$

(Differentiate (9-*iv*) and use the envelope theorem and the definition of the outside option.) This property might have some implication for regulation under incomplete information. A privately informed home-operating firm will normally require a rent above his outside option for revealing his information. A lesson from the new economics of regulation is that rent extraction can be accomplished by distorting net emissions away from first best. Hence, under asymmetric information type-contingent welfare will fall below first-best welfare, and perhaps to such a low level that the home government would like to have some of the firm types with the highest emission intensities to relocate.

Observation 2: Except for welfare, the first-best optimal allocation is unaffected by the distribution of ownership rights.

The fact that neither output nor net emissions depend on domestic ownership share α is due to the assumption that under complete information, the home government has the power to tax away any rent in excess of the outside option. This can be done, as we show below, through a two-part Pigovian tax, where the fixed part is used to extract the firm's rent in excess of its outside option.

Observation 3: The first-best emission path, $x^*(\theta)$, is increasing in emission intensity.

From *(9-i)*, along with *(ii)* and *(iii)* of *Lemma 2*, when using the definition of $\eta(y)$ we get, when $y^*(\theta) := Y(\theta, x^*(\theta))$:

$$\frac{dx^*(\theta)}{d\theta} = -\frac{(1+m)\cdot v''(Y+\theta Y_\theta)}{(1+m)\cdot v''\cdot(\theta Y_x - 1) - D''} = -\frac{(1+m)\cdot v''\dfrac{\pi' + Y\cdot\pi''}{\pi'' - \theta^2 v''}}{(1+m)\cdot v''\cdot(\theta Y_x - 1) - D''}$$

(11)

$$= \frac{(1+m)v''\pi'(y^*)\left[1-\eta(y^*)\right]}{(1+m)v''\pi'' + D''(\pi'' - \theta^2 v'')}$$

From *Lemma 1,we have* $\eta(y) > 1,\ \forall y \in [0, \tilde{y})$. Because the objective function is strictly concave in x, we get the result.

Observation 4: When net emissions, $x^*(\theta)$, obey the properties above, we have

- first-best output, $y^*(\theta)$, is declining in θ
- first-best pollution abatement, $[\theta y^*(\theta) - x^*(\theta)]$, is increasing in θ
- primary discharges, $\theta y^*(\theta)$, will be increasing in θ

(The more "dirty" technology the firm has installed, the less should be produced, but the higher should pollution abatement be. On combining *(9-i)* and the first-order condition underlying *(5)*, we have $(1+m)\pi'(y^*(\theta)) = \theta D'(x^*(\theta))$, for any $\theta \in \Theta$. Because the damage function is strictly convex, the RHS is strictly increasing in θ. Hence, marginal net revenue on the LHS has to increase in θ as well. Due to concavity if $\pi(y)$, output sold in the foreign market is therefore declining in θ. The second property stated in observation 4, follows then from (9-i) and strict convexity of both $D(x)$ and $v(\theta y - x)$, whereas the last property must necessarily hold because pollution abatement is increasing with emission intensity.)

Although implementation is not an important issue under complete information, it is useful for the subsequent discussion to see how this might be done. Suppose that some two-part (non-linear) emission tax is being imposed under complete information, with a fixed part (playing the role of an entrance or production fee) and a variable part relating pollution to the amount of taxes paid. Let the tax function be $T = t_0 + \frac{D(x)}{1+m}$, where the variable part is the environmental cost (privately valued), and the type-dependent fixed fee is equal to the private value of the maximal social surplus net of the firm's outside option; i.e. $t_0(\theta) = \frac{S(\theta, x^*(\theta))}{1+m} - R(\tilde{y}, \theta)$. (The fixed fee is declining in θ.) This extended emission tax will provide the firm with incentives so as to produce a socially desirable outcome.

4. Optimal Regulation under Incomplete Information

Suppose that the home government does not share the same information as the firm about emission intensity, at the stage when the government designs a pollution tax. At this stage it is assumed that the firm has already learnt the true value of θ. On the other hand the government does not know the type of the firm, but has, as mentioned above, prior beliefs as given by the distribution function $F(\theta)$.

In this model the emission intensity θ works through several channels. First it will have some impact on the firm's choice of output sold abroad, and hence on foreign revenue extraction. Secondly, it will have an impact on marginal abatement cost and will therefore influence the level of domestic pollution. Third, θ enters the firm's outside option, which is the main factor behind the firm's choice of relocation. The outside option will serve as a lower bound on rent left to the firm.

As is well known, an informed agent will try to take advantage of its private information so as to capture a rent. However, leaving a too high rent will be too costly; hence the home government may find it worthwhile to reduce ex post efficiency for the purpose of rent extraction. Within the present context, this means that if the government should propose the two-part tax scheme implementing the complete information solution, it is easy to show that any type of the firm would pretend to have the most emission intensive technology. Any firm with emission intensity in $[\underline{\theta},\overline{\theta})$, will gain by pretending to have the highest emission intensity, by producing a pollution level equal to $\overline{x} := x^*(\overline{\theta})$. The rent a θ-firm can obtain by pretending to have this technology, $u(\theta,\overline{\theta})$, turns out to be:

$$(12) \quad u(\theta,\overline{\theta}) = \pi(Y(\theta,\overline{x})) \; - \; v(\theta Y(\theta,\overline{x}) - \overline{x}) \; - \; \frac{D(\overline{x})}{1+m} \; - \; t_0(\overline{\theta})$$

By choosing net emissions $\overline{x}$, the firm pays the highest variable part of the tax, but the lowest fixed fee. In addition, the firm will take advantage of the gain in foreign net revenue due to a less restrictive emission requirement.

Define $V(\theta,x) := \pi(Y(\theta,x)) - v(\theta Y(\theta,x) - x)$, as the maximal pre-tax profits accruing to a θ-firm, with $V_\theta(\theta,x) = -Y(\theta,x)\cdot v' < 0$, $V_x(\theta,x) = v'(\theta Y(\theta,x) - x) > 0$.

Because $V(\overline{\theta},\overline{x}) - \dfrac{D(\overline{x})}{1+m} - t_0(\overline{\theta}) = R(\tilde{y},\overline{\theta}) = max_{\,\theta}\; R(\tilde{y},\theta)$, we can rewrite (12):

$$(12)' \quad u(\theta,\overline{\theta}) = R(\tilde{y},\overline{\theta}) \; - \; \left[V(\overline{\theta},\overline{x}) \; - \; V(\theta,\overline{x})\right] = R(\tilde{y},\overline{\theta}) \; - \; \int_\theta^{\overline{\theta}} V_z(z,\overline{x})\,dz \geq R(\tilde{y},\overline{\theta})$$

As $u(\theta,\overline{\theta}) \geq R(\tilde{y},\overline{\theta}) = Max_{\,\theta\in\Theta}\, R(\tilde{y},\theta)$, with strict inequality for any $\theta \in [\underline{\theta},\overline{\theta})$, a firm when confronted with the two-part pollution tax implementing the first-best solution, will find it profitable to pretend to be the one with the highest emission intensity. Hence the two-part tax scheme does not implement the first-best allocation under asymmetric information. It this tax scheme is used, we are left with too much pollution and a too high rent to the firm.

The central question now is: Can the government do it better? Is it possible to find an emission policy leading to separation and leaving the firm with a lower (expected) rent? What features will the environmental policy have that trades off rent extraction and efficiency, when the firm has a type-dependent outside option?

4.1 Incentive-compatible allocations

The idea is to choose within the class of truth-telling (or incentive compatible) mechanisms, the one that maximises expected social welfare, when taking account of the firm's type-dependent participation constraint as well.

At the first stage when the government offers a menu of contracts, the firm has already learnt the true value of its emission intensity. Because only taxes paid by the firm (*T*) and net emissions (*x*) can be verified, we can, according to the revelation principle restrict attention to a direct revelation mechanism that induces the firm to reveal its private information. Let the policy the government has committed to pursue be given by $\left\{T(\hat{\theta}),x(\hat{\theta})\right\}$, where $\hat{\theta}$ is the firm's report about its emission intensity. At the second stage of the game, the firm announces its emission intensity (which is equivalent to accepting a tax payment and some emission requirement) and chooses output sold abroad so that rent is maximised. At the final stage pollution is observed and the corresponding tax payment is made.

At the second stage of the game the firm's announcement $\hat{\theta}$ along with output will maximise its rent. However, according to lemma 2, it is common knowledge that the firm's choice of output will be $Y(\theta,x(\hat{\theta}))$ when announcing its type to be $\hat{\theta}$ (or equivalently, picking an emission requirement $x(\hat{\theta})$). Hence rent can be written as a function only of the true emission intensity and the one that is announced, as

$$(13) \quad u(\theta,\hat{\theta}) = \pi(Y(\theta,x(\hat{\theta}))) - v(\theta Y(\theta,x(\hat{\theta})) - x(\hat{\theta})) - T(\hat{\theta})$$

An incentive-compatible policy will induce $\hat{\theta}=\theta$, so that $U(\theta) := u(\theta,\theta) \geq u(\theta,\hat{\theta})$ for any type of the firm. As long as we restrict ourselves to continuously differentiable mechanisms, the following conditions must be satisfied:

$$(14\text{-}i) \qquad v'(\theta Y(\theta,x(\hat{\theta})) - x(\hat{\theta}))\cdot\frac{dx(\hat{\theta})}{d\hat{\theta}} - \frac{dT(\hat{\theta})}{d\hat{\theta}} = 0 \quad for \quad \hat{\theta}=\theta$$

$$(14\text{-}ii) \qquad v''(\cdot)\cdot\frac{dx(\theta)}{d\theta}\cdot\left[Y+\theta Y_{\theta}\right] \geq 0$$

Because the first-order condition *(14-i)* $\frac{\partial u(\theta,\hat{\theta})}{\partial\hat{\theta}} = 0$ must hold as an identity for $\hat{\theta}=\theta$, the second-order condition in *(14-ii)* follows from $\frac{\partial^2 u}{\partial\hat{\theta}\partial\theta} \geq 0$. According to *Lemma 2(iv)*, we have $Y(\theta,x)+\theta Y_{\theta}(\theta,x) > 0$; hence the second-order condition *(14-*

ii) is satisfied if $x(\cdot)$ is non-decreasing. It is well known that this monotonicity condition, along with the first-order condition *(14-i)*, will be sufficient for $\hat{\theta} = \theta$ to be a global maximum for the $\theta -$type.

The requirement of global incentive compatibility, $U(\theta) := u(\theta,\theta) \geq u(\theta,\hat{\theta})$ for any $(\theta,\hat{\theta})$, can therefore be represented by (FOC) and *(M)* below. On using the envelope theorem, the first-order condition in *(14-i)* can be expressed as (i) in lemma 3:

Lemma 3

Necessary and sufficient conditions for (global) incentive compatibility are:

(i) $\dot{U}(\theta) = -v'(\theta Y(\theta,x(\theta)) - x(\theta)) \cdot Y(\theta,x(\theta)) \quad (FOC)$

(ii) $x(\theta)$ non-decreasing *(M)*

The requirements of lemma 3 will be imposed as constraints (in addition to the participation constraint introduced earlier) in the government's optimisation problem, only for those types that are induced not to change location. For those types that should be induced to relocate, only the participation constraint has to be honoured.

4.2 The government's optimisation program

We should then be ready to solve the optimisation problem. However, one comment is required regarding what types should be wished "bon voyage". Under (*FPCI*) we had that any type of the firm should be induced to operate at home. Under incomplete or asymmetric information we know that the privately informed agent will require a rent above its reservation utility for revealing valuable information. To reduce expected rent, some distortion in the allocation will usually be required; hence social welfare is reduced below the first-best level for any type operating at home. This lesson along with *(10)*, and the assumption that outside option is increasing in emission intensity, should convince us that if some types should relocate, these types are to be found in the upper part of the type space Θ; i.e. among the firm types with the highest emission intensities.

A priori we assume the existence of some critical firm type, or a cut-off type, $\xi \in \Theta$, where ξ separates the type space into two disjoint sets, $[\underline{\theta},\xi]$ and $(\xi,\overline{\theta}]$, where all types in the first (second) set will be induced to stay (relocate).

The optimisation problem **[P]** is then: Choose an admissible emission path and a cut-off type so that expected welfare is maximised subject to the incentive constraints (including the type-dependent participation constraints):

[P]

$$Max_{\{x(\cdot),\xi\}} \left\{ \int_{\underline{\theta}}^{\xi} [S(\theta,x(\theta)) - \gamma U(\theta)] f(\theta) d\theta + \alpha \int_{\xi}^{\overline{\theta}} R(\tilde{y},\theta) f(\theta) d\theta \right\}$$

such that $\forall\, \theta \in [\underline{\theta},\xi]$ *and for* $\xi \in [\underline{\theta},\overline{\theta}]$

$$\dot{U}(\theta) = -Y(\theta,x(\theta)) \cdot v'(\theta Y(\theta,x(\theta)) - x(\theta))$$

$$U(\theta) \geq R(\tilde{y},\theta)$$

$$\dot{x}(\theta) \geq 0$$

where $S(\theta,x)$ *is defined as the social surplus; cf. (8)*

(Because rent to a complying firm must be declining in emission intensity, and because outside option is increasing, the problem can be solved as one with no "initial" conditions on the state variable *U*, i.e. $U(\underline{\theta})$ is "free", but with an "end-point" constraint as given by $U(\xi) \geq R(\tilde{y},\xi)$.) In [P], the choice variables or policy instruments are $\{x,\xi\}$, with one net emission level for each home-operating type, with a non-declining pollution path, while rent offered to the firm is the state variable. The first integral of the objective function is the expected net surplus produced by firms being induced to continue production at home when requiring an informational rent according to the incentive and the participation constraints. The second integral is the domestic share of the expected rent captured by firm types that relocate.
We could have solved this problem by using standard optimal control techniques. However, rather than applying the Maximum Principle directly, we will solve the problem in two stages. When doing this, we focus in the first stage on the optimal

emission level for an arbitrary domestic participation set or a fixed value of ξ in the interior of Θ. In the second stage we determine the mass of firm types that should be induced to relocate, by using ξ as a choice variable.

A convenient way to solve the first stage-problem is to define the virtual surplus, as given by:

$$(15)\quad \sigma(\theta,x) := S(\theta,x) - \gamma \frac{F(\theta)}{f(\theta)} Y(\theta,x)\, v'(\theta Y(\theta,x) - x)$$

We can interpret the virtual surplus, up to a constant, as the rent-adjusted social surplus. (See *A* in the appendix.) In the subsequent discussion the virtual surplus is assumed to verify; cf. *B* in the Appendix:

Assumption (C-VS): $\sigma(\theta,x)$ *is strictly concave in x*

Due to our assumptions, we have, for a fixed end-point (or cut-off type) $\xi \in \Theta$, that there will exist one and only one emission level that maximises the virtual surplus. We define this emission level, contingent on the fixed end point, as

$$(16)\qquad x(\theta;\xi) = \arg\ \max_{x \in (0,\, \theta\, \tilde{y})}\ \sigma(\theta,x)$$

In what follows we also impose the following assumption so as to ensure that the path determined by (16) will obey (*M*) lemma 3:

Assumption (M): Marginal abatement cost, $v'(\theta Y(\theta,x) - x)$*, is convex in* θ

(In *C* in the Appendix it is shown that this is sufficient for $x(\cdot;\xi)$ to obey (*M*).)

The first stage of the problem is then reduced to:

$$\textbf{(Sub - 1)}\quad Max_{\{x(\cdot),U(\xi)\}} \left\{ \int_{\underline{\theta}}^{\xi} \sigma(\theta,x(\theta)) f(\theta) d\theta - \gamma F(\xi) U(\xi) \,\middle|\, U(\xi) \geq R(\tilde{y},\xi) \right\}$$

The solution to this sub-problem must be characterised by a binding end-point constraint; i.e. $U(\xi) = R(\tilde{y},\xi)$ for any given cut-off point. The reason is of course that leaving rent is costly.

The optimal level of pollution requested by a θ-firm, $\theta \in [\underline{\theta},\xi]$, is derived from solving $\sigma_x(\theta, x(\theta;\xi)) = 0$, or equivalently

$$(17) \qquad S_x(\theta,x) - \gamma \frac{F(\theta)}{f(\theta)} \frac{d}{dx}\left[Y(\theta,x)v'(\theta Y(\theta,x)-x)\right] \;=\; 0$$

where $S_x(\theta,x) = (1+m)v'(\theta Y(\theta,x)-x) - D'(x)$ is the change in social gross surplus following a marginal change in net emissions. Should information be complete, optimal pollution would have obeyed $S_x(\theta,x) = 0$. In the present case, however, we have a correction term due to the desire to extract rent. According to lemma 2, it is easily seen that

$$(18) \quad \frac{d}{dx}\left[Y(\theta,x)v'(\theta Y(\theta,x)-x)\right] \;=\; Y_x\left[v' + \theta Y v''\right] - Y v'' = -v'' \cdot (Y + \theta Y_\theta) < 0$$

Hence, for any type of the firm operating at home, the government should induce over-pollution (relative to complete information); i.e. $x(\theta;\xi) \geq x^*(\theta)$, with equality only for the $\underline{\theta}$-type.

This distortion can be justified as follows: Let all types of the firm with emission intensity in some small interval $\left[\theta, \theta + \Delta\theta\right] := I_\theta$, in number $f(\theta)\Delta\theta$, increase their net emissions by Δx. We then have a direct change in social surplus, $S_x(\theta,x) f(\theta)\Delta\theta\,\Delta x = [(1+m)v'(\theta Y - x) - D'(x)] f(\theta)\Delta\theta\,\Delta x$, as the difference between increased net revenue (equal to the savings in abatement cost) and increased environmental damage. This marginal change in efficiency has to be balanced against the savings in expected inframarginal rent. When types in the interval I_θ are permitted to increase net emissions by Δx, the government can prevent types with a more superior technology, to pretend to have a (locally) more emission-intensive technology, at a lower cost. The number of firm types with emission intensity below

θ is $F(\theta)$. Hence the total expected savings in rent by increasing net emissions for types in I_θ, will therefore be $v''(\cdot)(Y+\theta Y_\theta)\Delta x\,\Delta\theta F(\theta)$, with a social value $\gamma v''(\cdot)(Y+\theta Y_\theta)\Delta x\,\Delta\theta F(\theta)$.

For any $\theta\in[\underline{\theta},\xi]$, net emissions should be pushed to a point (beyond first-best emission), where expected marginal loss in social surplus is equal to expected inframarginal savings in rent, as given in (17).

The solution above is conditioned on a fixed end-point ξ. Because the home government has the power to design the emission schedule (or its dual, the tax schedule) so as "to get rid of unwanted types", we have to solve the full problem with ξ as an endogenous variable. Let the value function of (Sub-1) be $\omega(\xi)$, and define total expected welfare in [P], for some $\xi\in[\underline{\theta},\overline{\theta}]$, as

$$(19)\qquad \Omega(\xi)=\omega(\xi)+\alpha\int_{\xi}^{\overline{\theta}}R(\tilde{y},\theta)f(\theta)d\theta$$

As $\Omega'(\underline{\theta})=W^*(\underline{\theta})f(\underline{\theta})>0$, due to (*FPCI*) and $x(\underline{\theta};\xi)=x^*(\underline{\theta})$ for any given end point, there will be a non-empty participation set under asymmetric information.
For a given end point, we have that rent to a θ-type can be expressed as

$$(20)\qquad U^{\xi}(\theta)=R(\tilde{y},\xi)\;+\;\int_{\theta}^{\xi}Y(z,x(z;\xi))\cdot v'(zY(z,x(z;\xi))-x(z;\xi))dz$$

Firm types with intensities below ξ will earn a rent above the reservation utility. As mentioned above, the necessity of giving away rent beyond what was required under complete information, along with over-pollution, will reduce welfare below what was attainable under complete information. Despite (*FPCI*), this property does not necessarily carry to incomplete information. Hence, the optimal solution under incomplete information might have the feature that some of the firm types with the higher emission intensity should be encouraged to relocate.

Use the notation $x^0(\theta) \equiv x(\theta;\xi^0)$, where $\xi^0 = arg\,max_{\xi\in\Theta}\,\Omega(\xi)$, and assume that $\frac{\Omega'(\xi)}{f(\xi)}$ is non-increasing for any $\xi \in \Theta$. (This condition is normally satisfied with our assumptions, as long as equilibrium rent is not too convex to the left of the end point. On the other hand, should it not be satisfied, the optimal participation set has to be determined on a global basis.) Given our additional requirement, the cut-off type will be fully determined by the condition $\Omega'(\xi^0) \geq 0$, with $\xi^0 = \overline{\theta}$ if strict inequality. We can express this condition in the following way:

$$(21)\;\; [S(\xi^0, x^0(\xi^0)) - \gamma\, R(\tilde{y}, \xi^0)] f(\xi^0) \geq \alpha\, R(\tilde{y}, \xi^0) f(\xi^0) + \gamma\, F(\xi^0)(-\dot{U}(\xi^0) - c'(\xi^0))$$

The interpretation of (21) is straightforward: On expanding the participation set from $[\underline{\theta}, \xi]$ to $[\underline{\theta}, \xi + \Delta\xi]$, $f(\xi)\Delta\xi$ more firms are included. The direct increase in net surplus is $[S(\xi, x^0(\xi) - \gamma\, R(\tilde{y}, \xi)] f(\xi)\,\Delta\xi$, which we recognise as the LHS of (21). This gain has to be balanced against the cost of getting more firms to operate at home. First, there is a loss in profits, as given by what could have been earned if these types in fact relocated. Because only a fraction (α) of the profits enters the welfare function, the direct cost of expanding the set of operating types at home will be given by $\alpha R(\tilde{y},\xi) f(\xi)\Delta\xi$; cf. the first term on the RHS of (21). In addition, rent to inframarginal firms, in number $F(\xi)$, has to be increased, both directly (for a fixed end-point constraint on the state variable *U*) and indirectly, through the higher outside option. The direct effect follows from the ordinary increase in rent for all inframarginal types when including $f(\xi)\Delta\xi$ more firms in the participation set, keeping $U(\xi)$ fixed. (This additional increase in rent is given by $(-\dot{U}(\xi))F(\xi)\Delta\xi$.) The indirect effect comes from the fact that that outside option is increasing. The new end-point constraint on the state variable will therefore increase, causing an additional increase in rent as given by $\frac{\partial R(\tilde{y},\xi)}{\partial \xi} F(\xi)\Delta\xi = -c'(\xi) F(\xi)\Delta\xi$. Hence the social cost of the additional rent is $\gamma[-\dot{U}(\xi) - c'(\xi)] F(\xi)\Delta\xi$, which we recognise as the second term on the RHS of (21).

Suppose that outside option is increasing "rapidly" with emission intensity so that ξ^0 will be in the interior of Θ. In that case we have the following result:

Proposition 2

Net emissions produced by the firm type with emission intensity in $[\underline{\theta},\xi^0]$*, will be higher than under complete information, as seen from the condition*

$$(17)' \quad (1+m)v'(\theta Y(\theta,x^0)-x^0)-\gamma\frac{F(\theta)}{f(\theta)}\frac{d}{dx}\Big[Y(\theta,x^0)\cdot v'(\theta Y(\theta,x^0)-x^0)\Big]=D'(x^0)$$

Furthermore, the mass of firm types operating at home will be reduced relative to complete information; cf. (21), which can be written as

$$(21)' \quad S(\xi^0,x^0(\xi^0))-(1+m)R(\tilde{y},\xi^0)-\gamma\frac{F(\xi^0)}{f(\xi^0)}\Big[-\dot{U}(\xi^0)-c'(\xi^0)\Big]=0$$

Whereas rent extraction is accomplished by distorting net emissions beyond the level that would have been optimal under complete information, the mass of firm types that are induced to relocate will normally increase, as well. Hence, the impact of incomplete information on expected pollution is ambiguous within the present context.

Furthermore, when using *lemma 2* together with the over-pollution result, any type of the firm is encouraged to increase its output. Because $x^0(\theta)\geq x^*(\theta)$ for any $\theta\in[\underline{\theta},\xi^0]$, with equality only for the firm with the lowest emission intensity, while domestic pollution will vanish all together for types that move, we have

$$(22) \quad \begin{cases} y^0(\theta)\equiv Y(\theta,x^0(\theta))\geq y^*(\theta)\equiv Y(\theta,x^*(\theta)) \quad \forall\theta\in[\underline{\theta},\xi^0] \\ y=\tilde{y} \quad \forall\theta\in(\xi^0,\overline{\theta}] \end{cases}$$

The upward distortion in net emissions is caused by the home government's desire to extract rent from the firm. Because the firm has full discretion as to how much to produce and sell of the final output abroad, domestic rent extraction is an indirect profit-shifting mechanism. Relaxing domestic environmental standards will put the firm in a more favourable competitive position in the foreign market. (Note that this effect will not be present in a regulatory context with output, as well as net emissions, being verifiable. As shown in Vislie (2001), the regulator would then induce the firm to produce less than under complete information, for any level of net emissions. Hence, profit shifting is an unintended effect of output being unverifiable.)

5. Some Comparative Static Results

Let us now see how the second-best optimal solution is affected by changes in some of the exogenous variables of the model; say a higher foreign ownership share (as given by $1-\alpha$), and more intense global competition (or weaker market power abroad), as measured by an increase in $\eta(y)$.

5.1 The impact of foreign ownership

From (17)' in proposition 2, we observe that foreign ownership does have a direct impact on the second-best allocation under asymmetric information, through the parameter γ. (Even if domestic taxation is non-distortionary, i.e. $m = 0$, foreign ownership, as given by the magnitude of $(1-\alpha)$, will make some distortions from first-best efficiency conditions socially desirable. This feature of the model is similar to regulation models where consumers' surplus and profits have unequal weights in the regulator's objective function; see for instance Baron (op.cit) and Laffont (1996).) We furthermore observe that rent extraction becomes more important the higher is the foreigners' ownership share, $1-\alpha$. If foreign ownership share should increase, the home government should allow the participating types to have higher net emissions (in order to reduce rent), but should also induce a higher fraction of the firm types to relocate. We might imagine that further globalisation of the world economy might lead to a more diversified ownership structure around the world. If the home government still has some opportunity to intervene in its own economy, say by internalising various local externalities, rent extraction will now play a more significant role for the home government. As $(1-\alpha)$ increases, a smaller share of the firm's rent will accrue to domestic owners. Therefore, the cost of leaving rent, as measured by γ, will increase. A rational government should therefore respond by sacrificing even more efficiency for the purpose of extracting rent. To compensate for the welfare loss of a lower α, the government will raise its tax revenue by inducing the firm to have higher net emissions.

Another implication of increased foreign ownership is that the mass of home-operating firms will go down. Highly emission-intensive types will be induced to move to jurisdictions with no (or lenient) environmental standards. Because net emissions will go up for types operating at home, but with a lower cut-off type, so that the interval $(\xi^0, \bar{\theta}]$ is broadened, we cannot state precisely how expected pollution is affected. We can summarise our findings as:

Proposition 3

Increased foreign ownership will lead to higher firm mobility, while leaving the remaining home-operating types with higher net emissions and lower emission intensity under incomplete information than under complete information.

(As long as the social cost of pollution abroad is lower, mobility of highly emission-intensive firms will improve global efficiency.)

5.2 The role of foreign market power

As mentioned above increased market power is modelled as an upward shift in the value of *A* which enters the unregulated profit-maximising output level $\tilde{y}$ in (1). A higher value of *A* will make both $\tilde{y}$ and the value of outside option $R(\tilde{y},\theta)$ higher, but more important here is that $A(y)$, and hence, $\eta(y)$, in lemma 1 will be lowered. In the subsequent analysis we let market power abroad be negatively correlated with the value of $\eta(y)$.

When considering the impact of a more intense global competition, causing the value of $\eta(y)$ to increase (weaker market power), the solution given in proposition 2 is affected. A weakening of the firm's market power, will work through a change in the incentive correction term (18), which on the other hand will affect the optimal pollution level, as determined in (17) or (17)'. Combining (18) with (iv) in lemma 2, we get

$$(23) \qquad S_x(\theta, x^0) + \gamma \frac{F(\theta)}{f(\theta)} v''(\cdot) \frac{\pi' \cdot (\eta - 1)}{-(\pi'' - \theta^2 v'')} = 0$$

The second term in (23) is positive (hence, over-pollution should be induced, as we have seen above) and will, cet. par., be higher, the higher is η. (The denominator in the second term is positive, because the firm's objective function is strictly concave.) We therefore have that rent extraction will be more important the weaker is the firm's market power. A weaker market power should motivate a rational government to relax the environmental standards. On allowing higher net emissions, the firm is encouraged to increase output, while pollution abatement is reduced. When exposed to a higher competitive pressure, the firm will loose net revenue. To counteract for this effect, the home government offers a less restrictive environmental policy. (In some sense this is, as above, a way of using environmental standards to improve the competitive position in the foreign market.) The response by the home government is qualitatively the same as under higher foreign ownership. In both cases rent extraction becomes more important. However, in the present case, higher competitive pressure will make revenue extraction abroad more difficult, which will indirectly affect the tax revenue the home government can collect. In order to raise valuable tax revenue, a less restrictive environmental policy is imposed. Again, lenient environmental standards will serve as a profit-shifting instrument.

As above, a higher competitive pressure will affect the set of home-operating types. For a given reservation utility, more competition would have led to more relocation of the most emission-intensive firms. However, there is a counteracting effect coming from a lower outside option, as $\tilde{y}$, and hence $R(\tilde{y},\theta)$, will be lowered. Because the cost of achieving separation is reduced, the distortions in net emissions can also be reduced. Therefore, the mass of home-operating firm types can increase when the firm is exposed to more intense competition abroad. Because there are opposing effects, we can conclude with:

Proposition 4

More intense competition abroad will make rent extraction more important, but because outside option will decrease, both distortions in net emissions and the mass of home-operating firms will be ambiguously affected.

(If outside option should be highly affected, so that rent requirement will be significantly reduced, the upward distortions in net emissions will be smaller, compared to a situation with less intense competition. The consequence will be a higher mass of home-operating types. On the other hand if $R(\tilde{y},\theta)$ is almost unaffected, more intense competition will affect the optimal allocation in the same manner as increased foreign ownership.)

6. Implementation

We are also interested in how the solution above can be implemented in a way similar to what we did under complete information.

Let the distribution of ownership rights be given and assume also that competitive pressure abroad is fixed. When the emission path strictly obeys *(M)* in lemma 3, the optimal solution under incomplete information can be implemented by a modified two-part pollution tax, as given by

$$(24)\quad t(x) = \frac{D(x)}{1+m} - \frac{\gamma}{1+m}\int_x^{\bar{x}} C(z)dz + \frac{S(\xi^0,\bar{x})}{1+m} - R(\tilde{y},\xi^0)$$

where

$$C(x) := \frac{F(\theta^0(x))}{f(\theta^0(x))}\left[Y_x(\theta^0(x),x)(v'(\cdot)+\theta^0(x)Y(\theta^0(x),x)v''(\cdot)) - Y(\theta^0(x),x)v''(\cdot)\right] \le 0$$

When constructing this tax schedule we have used that the optimal emission path $x^0(\theta)$, determined in (17)', is strictly increasing on $[\underline{\theta},\xi^0]$. Because the *M*-constraint is satisfied, we can define its inverse $\theta^0(x)$. We furthermore define $\underline{x} := x^0(\underline{\theta})$ and $\bar{x} := x^0(\xi^0)$, and because the emission path is differentiable on $(\underline{\theta},\xi^0)$, the tax function $t(x) := T(\theta^0(x))$ is a differentiable function defined on the interval $(\underline{x},\bar{x})$. (Given this tax function, no type of the firm will have any incentive to lie about itself.) The properties of this tax function follow from combining the firm's optimal response, as well as the optimality conditions (17) and (21)'.

The pollution tax in (24) consists of a fixed fee and an emission-contingent part. The fixed fee, which has a similar role as an entrance fee, is equal to the (private) value of social surplus net of rent for the marginal type. (The fixed fee under asymmetric information has the same flavour as under complete information, except for the fact that the fixed part in the latter case normally was higher and was designed according to the known type of the firm.) The variable part is the sum of environmental cost (privately valued) and a correction term capturing the interaction between net emissions and the cost of leaving rent to the firm. The latter part of the tax will exceed total environmental cost for any $x \in [\underline{x}, \bar{x})$, with no correction for an emission level $\bar{x}$. On the other hand, the marginal tax $t'(x) = \frac{D'(x)}{1+m} + \frac{\gamma}{1+m} C(x)$ is adjusted below the (private) value of marginal damage for any $x \in (\underline{x}, \bar{x}]$. (On increasing the net emissions, the firm will on the margin internalise a fraction of the savings in expected rent from higher pollution.)

When facing a pollution tax *t(x)*, a θ-firm will maximise rent, by solving:

$$(25)\quad Max\left\{ \ Max_{\ (x,y)} \ \{\pi(y) - v(\theta y - x) - t(x)\}\ ,\ R(\tilde{y}, \theta)\ \right\}$$

It is easy to verify that any type of the firm with emission intensity $\theta \in (\xi^0, \bar{\theta}]$ will choose to relocate, and so capture the outside option, rather than produce the maximal net emission level $\bar{x}$. If some type of the firm, $(\xi^0 + \Delta)$, outside the optimal participation set, should consider to stay in business and so produce the maximal amount of net emissions, $\bar{x}$, it will capture a rent below its outside option; as seen from $V(\xi^0 + \Delta, \bar{x}) - t(\bar{x}) < R(\tilde{y}, \xi^0) = V(\xi^0, \bar{x}) - t(\bar{x}) < R(\tilde{y}, \xi^0 + \Delta)$, due to the properties we have derived about the *V*-function.

Hence, the tax schedule proposed in (24) will implement the desired separation of the type space into those firms that will prefer to stay and those that prefer to move. On the other hand, types of the firm with emission intensity in $[\underline{\theta}, \xi^0]$, will benefit from staying by paying the tax, and produce according to the first-order conditions

$$(26)\qquad \begin{cases} \pi'(y) - \theta v'(\theta y - x) = 0 \Rightarrow Y(\theta, x) \\ \qquad v'(\theta y - x) - \frac{dt(x)}{dx} = 0 \end{cases}$$

so we have the final result:

Proposition 5

The two-part pollution tax t(x) in (24) will implement the constrained optimal solution in Proposition 2; i.e. $\forall\,\theta \in [\underline{\theta}, \xi^0]$

$$(27) \qquad (x^0, Y(\theta, x^0)) \in \arg\max_{(x,y)} \; \{\pi(y) - v(\theta\, y - x) - t(x)\}$$

7. Conclusions

A growing concern in modern societies is the influence by interest groups and professional lobbyists trying to capture public decision-makers. One example of a "successful" capture by lobbyists is the tax exemption Norwegian ship owners were granted a few years ago. This tax cut came as a result of "hard work" by the lobbyists. One of the means to get politicians to revise the original tax policy was by putting forth a threat that if taxes were not reduced, the ship owners would move abroad and relocate in jurisdictions with more favourable working and tax conditions. The ship owners got, not surprisingly, what they wanted. (There are probably a large number of similar stories from other countries.)

A closely related story, without introducing lobbyists as an explicit group of actors, has been told in this paper, within the field of environmental economics. The setting is an industry represented by a single firm (owned partly by foreigners and originally located within the jurisdiction of the home government), producing some negative externality (local pollution) jointly with the final output sold solely for export. The firm has private information both about emission technology and about its outside option, which is the profit net of set-up cost the firm can obtain by moving. (The modelling framework has been made as simple as possible by assuming that outside option is perfectly correlated with emission intensity. All conclusions hinge on this specific assumption. A natural further step, which is harder to solve, is to relax this assumption. The firm might then have countervailing incentives, and as shown by Jullien (op.cit.) it might be technically difficult to characterise the optimal solution, especially what types of the firm should be induced to relocate.)

The main purpose has been to characterise a second-best optimal environmental policy when the home government is restricted from using other tax instruments than a pollution tax. (Lump-sum taxation, as well as taxing profits, is not feasible.) The home government maximises a utilitarian objective function that is a weighted sum of domestic taxpayers' surplus and the share of the firm's rent accruing to domestic owners. Compared to a situation with complete information (under which any type of the firm is supposed to produce at home, while receiving a rent exactly equal to its outside option), asymmetric information will enable the firm to capture a socially costly rent. To reduce expected rent, the home government should induce over-pollution, as well as getting some of the most emission-intensive firm types to relocate. Rather than being convinced by the arguments of some interest group, the government should instead wish a subset of the firms "bon voyage". The economic consequences of a capture have to be borne by domestic citizens. Hence, relocation will, sometimes, be desirable, even if no relocation should be induced under complete information.

Another feature of the model is that it enables us to see the impact on domestic environment of "globalisation" of the world economy, through a change in ownership structure and weaker market power in the foreign market.

More influence of foreign owners will make rent extraction more important, having the implication that any home-producing firm should be induced to abate less (produce higher net emission), while at the same time a higher proportion of the firms should be induced to move. More fierce competition abroad will have a similar effect, but now the benefit from relocation will be reduced as well. The lower is the firm's outside option, the less expensive will it be to induce truthtelling. Weaker market power abroad will therefore have an ambiguous effect on the direction of the distortions and firm mobility, but asymmetric information itself should call for higher net emissions for those types that do not relocate.

Appendix

A. The derivation of the virtual surplus in (15)

The virtual surplus in (15) follows from using (i) in lemma 3, for some given cut-off type ξ and some given end-point constraint for the state variable: From (i) in lemma 3, and thereafter integrating by parts, we get

$$(A1)\;\; U(\theta) = U(\xi) + \int_{\theta}^{\xi} Y(z, x(z))v'(z\,Y(z, x(z)) - x(z))dz$$

Expected rent will therefore be determined as

$$(A2)\;\; \int_{\underline{\theta}}^{\xi} U(\theta) f(\theta) d\theta = F(\xi)U(\xi) + \int_{\underline{\theta}}^{\xi} Y(\theta, x(\theta))v'(\theta\,Y(\theta, x(\theta)) - x(\theta))\frac{F(\theta)}{f(\theta)} f(\theta)d\theta$$

Expected welfare from having the firm operating at home is then written as

$$(A3)\;\; \int_{\underline{\theta}}^{\xi} \left[S(\theta, x(\theta)) - \gamma\,U(\theta)\right] f(\theta)d\theta = \int_{\underline{\theta}}^{\xi} \sigma(\theta, x(\theta)) f(\theta)d\theta \;-\; \gamma\,F(\xi)U(\xi)$$

B. Properties of $\sigma(\theta,x)$

According to our complete list of assumptions the virtual surplus will be a continuously differentiable function of x, with

$$\sigma_x(\theta, x) = S_x(\theta, x) - \gamma\frac{F(\theta)}{f(\theta)}\left[Y_x v' + Y v''(\theta\,Y_x - 1)\right]$$
$$= (1+m)v'(\theta\,Y(\theta, x) - x) - D'(x) + \gamma\frac{F(\theta)}{f(\theta)} v''\left[Y + \theta\,Y_\theta\right]$$
$$= (1+m)v'(\theta\,Y(\theta, x) - x) - D'(x) + \gamma\frac{F(\theta)}{f(\theta)} v'' \frac{\pi'(1-\eta)}{\pi'' - \theta^2 v''}$$

The second equality follows from the firm's optimal choice of output, conditional on net emission, and (iii) in Lemma 2, whereas the third equality follows from (iv) in Lemma 2. The last term in the third line is non-negative. Because $Y(\theta, 0) > 0$, $S_x(\theta, 0)$ as well as $\sigma_x(\theta, 0)$ will be positive. Furthermore, for $x \to \theta\tilde{y}$, so that $Y(\theta,x) \to \tilde{y},$ it is easy to verify that

$\sigma_x(\theta,x) \to -D'(\theta\tilde{y}) + \gamma\dfrac{F(\theta)}{f(\theta)}v''\dfrac{\pi'(1-\eta)}{\pi'' - \theta^2 v''} \to -D'(\theta\tilde{y}) < 0$, because $\pi'(y) \to 0$ when $y \to \tilde{y}$. Due to (C-VS), there will, for each $\theta \in [\underline{\theta},\; \xi]$, with ξ arbitrarily fixed, exist a unique net emission level maximising $\sigma(\theta,x)$. Let this emission level, conditional on the critical type be $x(\theta;\xi) = arg\ max_x\ \sigma(\theta,x)$ which has to obey $\sigma_x(\theta,x(\theta;\xi)) = 0$, when the (*M*)-constraint is satisfied.

C. A sufficient condition for $x(\theta;\xi)$ to obey (M)

It is easy to see that given (C-VS), a sufficient condition for (M) to hold is that $\sigma_{x\theta}(\theta,x(\theta;\xi)) \geq 0$, because $\sigma_{x\theta} + \sigma_{xx}\dfrac{dx(\theta;\xi)}{d\theta} = 0$. A closer look at $\sigma_{x\theta}$ shows us that $\sigma_{x\theta}(\theta,x(\theta;\xi)) \geq 0$, if marginal abatement cost, $v'(\theta Y(\theta,x) - x)$, is convex in θ. Hence a sufficient condition for the (M)-constraint to hold is that $\dfrac{\partial}{\partial\theta}\left\{ v'' \cdot \left[Y + \theta Y_\theta \right] \right\} \geq 0$, when we have $\left[Y + \theta Y_\theta \right] > 0$ from Lemma 2. From (A5) we then get

$$\begin{aligned} \sigma_{x\theta} &= S_{x\theta} + \gamma \frac{\partial}{\partial\theta} \left\{ v''(\cdot) \cdot \left[Y + \theta Y_\theta \right] \right\} \\ (A6) \qquad &= (1+m)\, v''(\cdot) \cdot \left[Y + \theta Y_\theta \right] + \gamma \left\{ v'''(\cdot) \cdot (Y + \theta Y_\theta)^2 + v''(\cdot) \cdot (2 Y_\theta + \theta Y_{\theta\theta}) \right\} \end{aligned}$$

which is non-negative if $v'(\theta Y(\theta,x) - x)$ is convex in θ.

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