MEMORANDUM

No 18/2000

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By
Jon Vislie

ISSN: 0801-1117

Department of Economics
University of Oslo

This series is published by the
University of Oslo
Department of Economics

P. O.Box 1095 Blindern
N-0317 OSLO Norway
Telephone: + 47 22855127
Fax: + 47 22855035
Internet: http://www.sv.uio.no/sosoek/
e-mail: econdep@econ.uio.no

In co-operation with
The Frisch Centre for Economic Research

Gaustadalleén 21
N-0371 OSLO Norway
Telephone: +47 22 95 88 20
Fax: +47 22 95 88 25
Internet: http://www.frisch.uio.no/
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ENVIRONMENTAL REGULATION UNDER ASYMMETRIC INFORMATION WITH TYPE-DEPENDENT OUTSIDE OPTION

Jon VISLIE[1]

Department of Economics, University of OSLO

June 2000

e-mail: jon.vislie@econ.uio.no

Abstract:

We consider how a benevolent regulator should regulate a polluting export industry when the industry, having private information about its abatement efficiency, has an option to move its operations abroad, with a type-dependent outside option rent. The paper focuses on the case where outside option is negatively correlated with abatement efficiency, implying unilateral incentives for overstating abatement efficiency. Because lump-sum taxation is ruled out, rent will have a social cost which is also affected by foreign ownership to the industry. It is demonstrated that optimal regulation calls for excessive pollution among the participating types (relative to complete information), for the purpose of rent extraction, while types being excluded are the ones with the higher outside option (the least efficient types). We also demonstrate that with a higher foreign ownership share, the larger is the set of excluded types, while overpollution should be reduced.

Keywords: Asymmetric information, environmental regulation, foreign ownership, type-dependent participation constraints.

JEL classification: D62, D82, D78, L51

1. Introduction

Increased international mobility of firms might create new problems for domestic governments when trying to implement policies that interfere with firms' ability to make profits at home. Higher international mobility and tax competition between countries impose a new set of restrictions on how to design tax systems. Furthermore, domestic regulation of firms might also be affected by increased international mobility. If a domestic government should want to impose, say, stricter environmental regulation so as to cope with local pollution, firms that will be affected by regulation might argue for exemption by threatening to move their operations abroad, where regulation is softer. An option of switching location is a way to bypass domestic regulation. However, it is reasonable to believe that a rational domestic government should not respond with exemption from any domestic regulation to the industry's exit threat, we observe that the government now and then takes a rather weak position against such threats, by deciding not to impose any regulations at all, which interfere with allocative efficiency. (This will sometimes be an irrational response, and might be the outcome of regulatory capture.) Tax competition between countries is another example that has demonstrated that governments cannot impose tax rules without taking into account the exit threats put forth by mobile firms in response to unfavourable tax rules.
In this paper we want to analyse the scope of a benevolent regulator or government in designing a domestic environmental policy, when the polluters are threatening to move their operations abroad. We will consider this issue within a context where an export industry located in a country, is producing some local pollution. When social costs are to be internalized, e.g. through levying taxes, the harmed industry has the option of complying with the domestic regulation or set up a new plant within a jurisdiction with softer regulation. During the last decade this has been a common observation in many countries. Due to lower mobility costs, firms with highly mobile capital, have been exempted from higher taxes as the governments have regarded these threats as credible as well as exit itself has been considered undesirable.

The main focus of the paper is the design of optimal environmental regulation of some industry generating a negative externality through local or domestic pollution, within a context of asymmetric information, with respect to the industry's emission technology as well as the ability to exit, as measured by the cost of mobility or cost of relocating. The paper owes a lot to previous papers analysing various aspects of environmental regulation under asymmetric information; e.g. Baron (1985a,b), Lewis (1996), Roberts and Spence (1976) and Spulber (1988). The industry, which we for simplicity will regard as a single economic agent, has an option to operate in a completely unregulated jurisdiction, after having incurred some exit or set-up cost. But because this cost is assumed to be private information as it is type-dependent, the reservation utility or participation constraint will be type-dependent as well. (See Laffont and Tirole (1990), Maggi & Rodríguez-Clare (1995), Jullien (1999) and Curien et al. (1998) for more on regulation with type-dependent reservation utility.)

The impact of environmental policies on plant location has been analysed by several authors; e.g. Motta and Thisse (1994) and Hoel (1997), for an imperfectly competitive environment and symmetric information within a two-country, two-firm, one-commodity context. For instance, Motta and Thisse show that the structure of the fixed set-up costs will have major implications for the possible delocation of the home firm when the domestic government imposes a strict environmental policy. Hoel analyses a two-stage game for an environment with local pollution (as in the present paper), where each government first decides on a set of emission taxes, whereas the firms in the second stage of the game decide where to locate. These papers are more or less discussing the impact of ”environmental dumping” as an instrument to attract foreign investments, within an imperfect environment, but with symmetric information. The present paper takes the opposite view as the aim is to design environmental policy rules under asymmetric information both about emission technology (which has been analysed by Laffont (1994) and others) as well as about the outside option, due to private information about the mobility cost. In addition we analyse the role of foreign ownership to the industry and ask in what way foreign ownership will affect domestic environmental regulation. In Vislie (1999) the role of foreign ownership is analyzed, but with no outside option. It is demonstrated that foreign ownership will have an impact on domestic environmental regulation under asymmetric information about emission technology, even when domestic taxation is non-distortive. The more of the industry that is owned by foreigners, the higher is the welfare cost of rent, which makes rent extraction more important. Because foreigners' rent does not enter the objective function of the home government, rent extraction now calls for larger distortions from first best, so that less pollution abatement should be induced. A similar distortion will appear when the firm has an option to relocate, but now we show that, if exit should be socially desirable, some of the least efficient types (i.e. the ones with the higher outside option) should be induced to move.

The paper is organised as follows: In section 2 we present the basic framework of the model with an industry located in a country, producing a fixed output sold solely for export. A by-product of the activity is generation of local pollution, which (prior to abatement) is proportional to output. Even though we assume a fixed relationship between primary discharges and output, this relationship is modified by the industry when undertaking non-verifiable abatement. To focus merely on environmental regulation, we impose a strong assumption that output is fixed which might of course be too restrictive, but it helps making the model tractable. The industry is owned partly by domestic citizens, with an exogenously given ownership share, and the government's objective is to maximize the sum of consumers' (or tax-payers') surplus and the share of rent accruing to domestic owners of the industry. First-best allocation, which is a benchmark solution, is derived. In section 3 we analyse the more interesting problem when the industry has private information about emission technology and reservation utility (due to private information about the exit cost), which plays the role as an outside option. The type-dependent reservation utility, which is the rent the industry can achieve by choosing the exit option, is assumed to be negatively correlated with abatement efficiency, in the sense that a dirty industry can relocate at a lower cost than a clean industry. This assumption is of course only one of many possibilities, but helps us to reduce the equilibrium set, as there are no countervailing incentives. Hence we can focus merely on what types should be excluded, by making use of standard techniques. When efficiency and outside option are negatively correlated, we show that ownership structure will matter under asymmetric information, both with regard to the distortions being imposed for the purpose of rent extraction, and to the extent of types that should be induced to relocate. We also show how the optimal solution can be implemented through a Pigovian tax. Section 4 concludes.

2. The model

Consider an export industry (regarded as a single economic agent) located in a country, called the home country. The good produced by the industry is fully exported (no domestic consumption), and the industry is by assumption owned by domestic citizens, with an exogenous ownership share $\alpha \in [0, 1]$. To focus on environmental regulation alone, we will assume that the industry is committed to produce a given amount of the output, y^0, normalised to one. Net revenue from exporting one unit of the output is π^0. Along with the given level of output, primary discharges (”gross emission”) are generated. We assume that primary discharges are proportional to output, with a factor of proportionality θ, with θ being a continuous one-dimensional technology parameter, known only by the industry, with a type space $\Theta = [\underline{\theta}, \overline{\theta}]$. Hence, θ denotes the amount of primary discharges (prior to abatement) produced by a θ-industry. The lower θ is, the cleaner is the industry’s technology, as the level of emissions per unit output, prior to abatement, is smaller. Net emissions, denoted x, will be equal to the difference between the amount of primary discharges θ and pollution abatement $A := \theta - x$. Although a fixed relationship between the level of primary discharges and output is assumed, the final level of net emissions can be modified through costly, but unverifiable, pollution abatement. Let the cost of abatement be v(A) which is thrice continuously differentiable, strictly increasing and strictly convex for any positive value of A, with $v(0) = v'(0) = 0$. (We also assume $v'''(A) \geq 0$.) The social damage or domestic environmental cost caused by net emissions is given by the function D(x) which is twice continuously differentiable, strictly increasing and strictly convex for any $x > 0$, with $D(0) = D'(0) = 0$. The pollution is local or country-specific.

Because we want to analyse optimal environmental regulation under asymmetric information when the industry threatens to move its operations abroad if domestic regulation becomes too unfavourable according to the industry owners, we have to specify the industry’s options. We make a strong assumption that if the industry chooses to close down its domestic plants and move its operations to another location, the regulation within the new jurisdiction is extremely favourable to the industry, as no regulation will be imposed. Relocation is then due to environmental dumping by some other government as the home country imposes too strict environmental regulation, from the industry’s point of view. Then if moving abroad, the industry will capture its maximal profit π^0, but will have to incur a type-dependent exit or set-up cost c(η), where η is a parameter indicating the industry's ability to switch location. This mobility cost is normally private information and can be seen to capture the cost disadvantage from operating abroad rather than at home. In order to see the impact of such an outside option, we make another strong assumption by restricting the dimension of the type space. We assume that $\eta = \theta$; hence ability to switch location is perfectly correlated with the efficiency in emission technology. (A natural extension of the problem is to analyse the general contracting problem with multi-dimensional type space; cf. the approach developed by Armstrong (1999) and Armstrong and Rochet (1999). However, at the present stage we want to avoid these complications.) If choosing a new location, the industry has a rent or net utility as given by

(1) $$U^{out} = \pi^0 - c(\eta) := R(\eta), \text{ where } \eta = \theta$$

We assume that $R(\theta) > 0$ for any $\theta \in \Theta$. The domestic government does not tax the net profit earned by the industry when operating within the new jurisdiction. We assume $c(\cdot)$ to be twice continuously differentiable in θ, and $c'(\theta) < 0$, so that $R(\theta)$ is strictly increasing in θ. (One justification for this R-function might be that a clean industry has to make use of some specific factors not required by a dirty one, implying that the cost of switching location will be higher the smaller is θ. If $c'(q) > 0$, then there might be countervailing incentives, and as demonstrated by Jullien (op.cit.), it becomes a bit harder to derive a solution.)

If the industry finds it more attractive to stick to its original location, where some regulation is imposed, including paying taxes (which will be type-dependent) and complying with environmental regulation, net utility or rent is

(2) $$U^{in} = \pi^0 - v(\theta - x) - T$$

where T is the amount of taxes paid to the domestic government, when producing one unit of the output for export with net emissions x.

The consumers' or tax-payers' surplus will also depend on whether the firm will stay or move. We rule out lump-sum taxation. Hence any tax revenue collected from the industry has a social value (1 + m)T, where m is a positive shadow cost of public fund. When the industry chooses to stay, generating local pollution x with a social cost D(x), while paying taxes T, the consumers' surplus becomes $CS^{in} = (1 + m)T - D(x)$.
On the other hand, if the industry chooses to exit, so that no local pollution is generated and no tax revenue is collected, consumers' surplus will vanish, with $CS^{out} = 0$.

We let the welfare measure be the sum of consumers' (or tax-payers') surplus and the domestic share of the industry's net utility or rent. Let the "tax-adjusted" welfare weight put on rent be $\gamma := 1 + m - \alpha > 0$. We then have

(3-i) $$W^{in} = CS^{in} + \alpha U^{in} = (1 + m)[\pi^0 - v(\theta - x)] - D(x) - \gamma U^{in} := S(\theta, x) - \gamma U^{in}$$

When the industry chooses to stay, welfare consists of the social value of profits (net of abatement cost), environmental cost and the weighted social cost of rent left to the industry. Given our assumptions, W^{in} is concave in (x, U), with the following property of the first-order derivative $S_x(\theta, x) = (1 + m)v'(\theta - x) - D'(x)$, which is positive (negative) for x = 0 (for $x = \theta$, respectively).

If the industry chooses to relocate, welfare becomes the domestic share of rent obtained from operations abroad

(3-ii) $$W^{out} = CS^{out} + \alpha U^{out} = \alpha R(\theta)$$

When information is complete and symmetric, maximal welfare W^* will be determined from

(4) $$W^* = \text{Max}\ \{\alpha R(\theta), \text{Max}_{x,U}\, [S(\theta, x) - \gamma U \mid U = U^{in} \geq R(\theta)]\}$$

Define $x^*(\theta) = \text{argmax}_{\,x\in[0,\,\theta]}\ \{S(\theta, x) - \gamma R\} \in (0, \theta)$, and suppose that for any $\theta \in \Theta$, we have $S(\theta, x^*) - \gamma R(\theta) > \alpha R(\theta)$, or equivalently, $v(\theta - x^*) + \dfrac{D(x^*)}{1+m} < c(\theta)$, saying that minimised sum of abatement cost and (the private value of) environmental cost is below the private cost of relocating for any type of the industry. In that case, no relocation should be induced under complete information, under which no rent above R should be offered to the industry.

(According to our assumptions we easily see that for any type θ, the level of net emissions x^* that will minimise total social cost $\{D(x) + (1 + m)\ v(\theta - x)\}$ will be in the open interval $(0, \theta)$.) The first-best solution can then be summarised in the following proposition:

Proposition 1. *Given our assumptions, the optimal allocation under complete information* $\{x^*, U^*, W^*, \ \forall \theta \in \Theta\}$ *is characterised by*

(5-i) $(1 + m)v'(\theta - x^*) - D'(x^*) = 0$

(5-ii) $U^*(\theta) = R(\theta)$

(5-iii) $W^*(\theta) = S(\theta, x^*(\theta)) - \gamma R(\theta) > \alpha R(\theta) \ \Leftrightarrow\ \dfrac{D(x^*)}{1+m} + v(\theta - x^*) < c(\theta)$

telling (in a familiar way) that net emissions should be set so that social marginal abatement cost equals marginal environmental cost (cost efficiency), no rent above the value of the outside option should be offered to the industry, while social welfare produced by an industry operating at home exceeds (by assumption) the social value of the outside option. Hence, irrespective of type, full participation should be induced under complete information. We also note that first-best pollution is independent of ownership structure, as measured by α, with the emission path $x^*(\cdot)$ being increasing in θ. We observe directly from (5-i), when using that social cost $\{(1 + m)v(\theta - x) + D(x)\}$ is strictly convex in x, that $\dfrac{dx^*(\theta)}{d\theta} = \dfrac{(1+m)v''}{(1+m)v'' + D''} \in (0,1)$. Hence abatement under complete information, $A^*(\theta) = \theta - x^*(\theta)$, should itself be increasing in θ, making it socially desirable to get a clean industry to abate less than a dirty one. Furthermore, pollution will be higher, the more distortive is domestic taxation (i.e. the higher m is).

At last, given our assumptions, maximal social welfare $W^*(\theta)$, which will be higher the more of the industry is owned by domestic citizens, will be declining in θ; as seen from

$$(6) \qquad \frac{dW^*(q)}{dq} = -(1 + m)v'(\theta - x^*(\theta)) - \gamma R'(\theta)$$

(Due to (6) we guess that if some industry types should be induced to relocate, we find these among the least efficient ones.) This first-best allocation can be implemented by imposing a Pigovian or pollution tax $\tau(x) = \frac{D(x)}{1+m}$ along with some fixed transfer so that no rent above R is left to the owners of the industry.

Let us have this first-best solution as a benchmark when turning to asymmetric information about the emission technology, when the industry has an outside option, which is increasing in θ. As relocation is possible, the industry has a bypass opportunity, which should be taken into account by the regulator when designing the regulatory scheme under asymmetric information. The bypass opportunity follows from the assumption that some countries practice environmental dumping, with no environmental (or any other) kind of intervention. Our main focus is to see how domestic environmental regulation will be affected by private information about the emission technology, combined with a type-dependent increasing reservation utility, as well as ownership structure.

3. Optimal regulation under asymmetric information and increasing outside option

Suppose that the industry is privately informed about the parameter θ, which is related both to emission technology and to the outside option. Because output is fixed, the model will be a slight modification of the single-product regulation model developed by Laffont and Tirole (1993; chapt. 1). We assume that net emissions are verifiable, but that abatement as well as abatement cost is not. The interesting aspect of the model, is the inclusion of an outside option, making the industry's reservation utility type-dependent. The main issue to be focused upon is how this outside option, along with ownership structure, will affect optimal regulation with a privately informed industry. It is expected that full participation, as was imposed under complete information, will not necessarily carry over to the present situation. (As noted by many authors, underparticipation is a common feature in many adverse selection models.) Hence, the regulator might induce some types to leave, and a conjecture when R is increasing, is that if exclusion should be desired, then a subset of the least efficient types should relocate.

The regulator does not know the industry's type, but has prior beliefs, which are common knowledge, given by the strictly increasing and twice continuously differentiable cumulative distribution function F(θ), with density f(θ) > 0 on the fixed support $\Theta = [\underline{q}, \bar{q}]$, satisfying the property of log-concavity of F, so that the following property holds:

Monotone hazard rate (MHR): $\frac{d}{dq}\left(\frac{F(q)}{f(q)}\right) \geq 0$

The regulator knows that the industry will take advantage of its private information to capture a socially costly rent when it chooses not to move its operations abroad. To counteract the incentives for misrepresentation, the regulator will in general offer a set of contracts that is distorted relative to what would have been offered under complete information, so as to extract costly rent from the industry. The problem is therefore to design a mechanism so that the industry will reveal its private information at the lowest possible cost to society. According to the revelation principle, any mechanism can be represented by a direct revelation mechanism, where the industry is asked to report its type. The regulator is, by assumption, able to design (and commit to) a mechanism so as to induce truthtelling.

Let the set of types being induced to continue the operations at home be $\Xi \subseteq \Theta$. Keep this set fixed for a moment, later it will be determined as part of the optimal solution. For any θ, the regulator offers a pair $\{T(\hat{q}), x(\hat{q})\}$, i.e. a transfer and net emissions for any report $\hat{q}$ of the industry's type.

Necessary and sufficient conditions for incentive compatibility, i.e. $U(\theta) := u(\theta, \theta) \geq u(q, \hat{q}) := \pi^0 - v(\theta - x(\hat{q})) - T(\hat{q}), \forall (q, \hat{q})$ are:

(7-i) $\frac{dU(q)}{dq} = -v'(q - x(q))$; (first-order condition for local optimality)

(7-ii) x(θ) non-decreasing; (second-order condition or monotonicity)

as long as U(θ) ≥ R(θ) ∀θ∈ Ξ. (Types that refuse the offer put forth by the regulator will move abroad. Let the complementary set, possibly empty including types that relocate, be Σ.)

We have established that the two conditions in (7) will hold as long as U(θ) ≥ R(θ). In general, the mechanism will have to take account of the interaction between the incentive constraint (IC) and the participation constraint (PC) when the latter is type-dependent. The mechanism for types in Ξ has to obey U(θ) ≥ Max {R(θ), u($q, \hat{q}$) } for any pair {$q, \hat{q}$ } when $\hat{q} = q$.

Substituting for T, we can formulate the regulator's problem as maximising expected welfare subject to the incentive compatibility constraint, the participation constraint, and the set of types that should remain staying at home:

[RP]

$$\text{Max}_{x(\cdot),\Xi} \int_{\Xi} [S(q, x(q)) - gU(q)] f(q) dq + \alpha \int_{\Sigma} R(q) f(q) dq$$

s.t.

$\frac{dU(q)}{dq}$ = – v′(θ – x(θ))

x(θ) non-decreasing; x∈[0, θ]

U(θ) ≥ R(θ), when (IC) binds

U(θ) = R(θ), when (PC) is binding

U(θ) continuous on Θ, with Ξ⊆Θ

Because R(θ) is assumed strictly increasing, whereas U itself is decreasing when IC binds, we expect that if some types are to be excluded, these will be found in the upper part of the distribution; hence our conjecture is that $\Sigma = (x, \bar{q}\,]$ where ξ ≥ q .

With an increasing outside option, we can immediately establish that the first-best solution cannot be implemented under incomplete information. Any industry with θ strictly below $\bar{q}$, will find it profitable to take the first-best contract, if offered, designed for the $\bar{q}$ -type, and thereby achieve an informational rent, as given by

u(θ, $\bar{q}$) = R($\bar{q}$) + v($\bar{q} - x^{*}(\bar{q})) - v(q - x^{*}(\bar{q}))$ > R($\bar{q}$) = Max $_{\theta\in\Theta}$\{R(θ)\}.

Hence, when R(θ) is increasing, the industry has an overall incentive to overstate its type. To induce truthtelling, rent offered to any type in the set Ξ, must be modified, which is embodied in the state equation (7-i). Because rent required for truth-telling, U(θ), should be declining in θ, the participation constraint, U(ξ) ≥ R(ξ) which normally holds with equality in the optimal solution, will, among the types that participate, bind only for one type. (For types that relocate, we trivially have U = R.)

Keep for a moment the upper bound ξ in the set Ξ fixed, and define the value function for the active types as V(ξ, R(ξ)),

[RP-Ξ]

$$V(\xi, R(\xi)) := \text{Max}_{x} \int_{\underline{q}}^{x} [S(q, x(q)) - gU(q)] f(q) dq$$

s.t., for any θ ∈ Ξ = $[\underline{q}, x]$

$$\frac{dU(q)}{dq} = -v'(q - x(q))$$

U(θ) ≥ R(θ), x∈[0, θ] and x(θ) non-decreasing

The control variable is x whereas U is the state variable of the problem. Let λ(θ) be the costate variable of the state equation. Furthermore, q and Q are non-negative multipliers associated with the constraints on the control region; x ≥ 0, and x ≤ θ, respectively. (We ignore for a moment the monotonicity constraint on x; later additional restrictions are imposed so that the proposed candidate will satisfy this constraint.) The Hamiltonian is then

(8) $$H(\theta, x, U, \lambda) = \{S(\theta, x) - \gamma U\} f(\theta) - \lambda v'(\theta - x)$$

where S(θ, x) = (1 + m)[π^0 – v(θ – x)] – D(x), and the Lagrangean defined as

$$\text{(9)} \qquad L(\theta, x, U, \lambda, q, Q) = H(\theta, x, U, \lambda) + qx - Q(x - \theta)$$

Necessary conditions for ($\hat{x}, \hat{U}$) to solve the modified problem, are: For any θ∈Ξ,

$$\text{(10-i)} \qquad \frac{\partial L(q, \hat{x}, \hat{U}, l, q, Q)}{\partial x} = S_x(\theta, \hat{x})\, f(\theta) + \lambda(\theta) v''(\theta - \hat{x}) + q - Q = 0$$

$$\text{(10-ii)} \qquad q \geq 0 \; (= 0 \text{ if } \hat{x} > 0); \; Q \geq 0 \; (= 0 \text{ if } \hat{x} < \theta)$$

$$\text{(10-iii)} \qquad \frac{d\,l(q)}{dq} = \gamma f(\theta) \Rightarrow \lambda(\theta) = \gamma F(\theta) + k$$

We can immediately establish that because R is increasing in θ while U is decreasing, with U(θ) ≥ R(θ), the pure state constraint can be expressed as U(ξ) ≥ R(ξ), which must hold with equality for the optimal solution; hence k = 0 as $U(\underline{q}) > R(\underline{q})$. (If we furthermore assume v″(0) to be sufficiently small and/or D′(θ) being sufficiently high for any θ, it can easily be shown that $\hat{x} \in (0, \theta)$ for any θ∈Ξ; hence q = Q = 0.) Then the optimal emission profile $\hat{x}(q)$ has to obey the following condition:

$$\text{(11)} \qquad (1 + m)v'(\theta - \hat{x}(q)) - D'(\hat{x}(q)) + g\,\frac{F(q)}{f(q)}\,v''(q - \hat{x}(q)) = 0$$

This condition reflects the familiar trade-off between allocative inefficiency and rent extraction. To reduce rent to types that will benefit from misrepresenting their true type (i.e. for types having low values of θ), the regulator will induce higher net emissions (as compared to first best) so as to make it less profitable for the cleaner types to take advantage of their superior abatement technology. (When increasing x, the slope of the rent function U is increased or becomes less negative.) The last term in (11), which is a non-negative incentive correction term, captures the impact on reduced expected rent (for all types below θ), from allowing a θ-type to pollute marginally more. (As usual, there is no distortion for the most efficient type ($\underline{q}$).) Note that because we have assumed $\hat{x}$ to be in the interior of the control region, and that the Hamiltonian is strictly concave in x, the path $\hat{x}(q)$ will be the unique solution to [RP-Ξ], if that path is non-decreasing on Ξ as well. We can express (11) as $\frac{S_x(q,\hat{x}(q))}{v''(q-\hat{x}(q))}+g\,\frac{F(q)}{f(q)}=0$. Due to strict concavity we have $\frac{\partial}{\partial x}(\frac{S_x(q,x)}{v''(q-x)})<0$, and with the imposed restrictions on the v-function we have $\frac{\partial}{\partial q}(\frac{S_x(q,x)}{v''(q-x)})>0.$ These properties combined with MHR will then be sufficient for the emission path being increasing in θ, and therefore obey the monotonicity constraint (7-ii). We therefore have:

Proposition 2. *Given our assumptions, the emission path implicitly determined in (11), with the associated rent obeying (7-i), will for an arbitrary participation set X Í Q, be the unique optimal separating solution to the regulation problem with outside option being increasing in q.*

Before turning to the optimal cut-off, let us point out that the second-best optimal emission path will depend on ownership regime, through the impact of α on the welfare cost of rent, γ. In the previous section we have established that optimal pollution under complete information was independent of ownership structure. This ”irrelevance of ownership regime” does not carry over to incomplete information. The more of the industry that is owned by foreigners (i.e. the smaller α is), the higher is the welfare cost of rent, γ, which cet.par., makes rent extraction more important, as foreigners' rent does not enter the objective function. The implication is then that less pollution abatement should be induced (leading to excessive pollution for those types that do not relocate), the more of the industry is owned by foreigners; cf. Laffont (1996):

Corollary 1. *Environmental regulation under incomplete information is affected by ownership regime, through the impact of the foreign ownership share on the welfare cost of rent. Even if domestic taxation is non-distortive, foreign ownership alone will make some deviations from first best socially desirable. When information is complete, ownership was shown to be irrelevant.*

Let us now turn to the issue of finding the optimal cut-off type ξ. When going back to [RP], and when making use of the value function of the modified problem, the optimal cut-off type is determined from solving the following problem:

Optimal Cut-off: $\quad \text{Max}_{\xi \in \Theta} \{V(\xi, R(\xi)) + \alpha \int_{x}^{\bar{q}} R(q) f(q) dq \; := w(\xi)\}$

In order to find the upper bound of the set of participating types Ξ, let us use some sensitivity results from Seierstad and Sydsæter (1987; Theorem 9, chapter 3). They establish that:

(12-i) $$\frac{\partial V(x, R(x))}{\partial x} = H(x, \hat{x}(x), \hat{U}(x), l(x))$$

(12-ii) $$\frac{\partial V(x, R(x))}{\partial R(x)} = -l(x)$$

Hence to find the optimal cut-off type, we have to consider

(13)
$$\frac{dw}{dx} = \{(1 + m)[\pi^0 - v(\xi - \hat{x}(x))] - D(\hat{x}(x)) - \gamma R(\xi)\}f(\xi)$$
$$- \gamma F(\xi)v'(\xi - \hat{x}(x)) - \gamma F(\xi)R'(\xi) - \alpha R(\xi)f(\xi)$$
$$= [S(\xi, \hat{x}(x)) - g\frac{F(x)}{f(x)}v'(x - \hat{x}(x))]f(x) - g[R'(x)F(x) + R(x)f(x)] - aR(x)f(x)$$

We claim that $\xi > \underline{q}$. If not, the following must be true: $S(\underline{q}, \hat{x}(\underline{q})) - \gamma R(\underline{q}) - \alpha R(\underline{q}) = S(\underline{q}, \hat{x}(\underline{q})) - (1 + m)R(\underline{q}) \le 0$, as $x^*(\underline{q}) = \hat{x}(\underline{q})$. This contradicts (5-iii); hence we have $\xi > \underline{q}$, and at least a subset of the most efficient types should be induced to continue production at home.

The optimal cut-off type $\hat{x}$ is therefore found as the solution to

$$\frac{1}{f(\hat{x})}\frac{dw(\hat{x})}{dx} = S(\hat{x},\hat{x}(\hat{x})) - g\frac{F(\hat{x})}{f(\hat{x})}[v'(\hat{x}-\hat{x}(\hat{x}) + R'(\hat{x})] - (1+m)R(\hat{x}) \geq 0$$

(13)’

$$\text{with } \frac{dw}{dx} = 0 \text{ if } \underline{q} < \hat{x} < \overline{q} \text{ and } \frac{dw}{dx} \geq 0 \text{ if } \hat{x} = \overline{q}$$

From the definitions of R and γ, the expression in (13)’ can be written as

$$\frac{1}{f(\hat{x})}\frac{dw(\hat{x})}{dx} = (1+m)\{c(\hat{x}) - v(\hat{x}-\hat{x}(\hat{x})) - \frac{D(\hat{x}(\hat{x}))}{1+m} - \frac{1+m-a}{1+m}\frac{F(\hat{x})}{f(\hat{x})}[v'(\hat{x}-\hat{x}(\hat{x})) - c'(\hat{x})]\}$$

Due to the full participation-condition under complete information, (5-iii), we established that $\hat{x} > \underline{q}$. Whether full participation will carry over when information is incomplete, depends on comparing the private cost of relocation c on the one hand to the sum of abatement cost, the (private) cost of pollution and the inframarginal increase in expected rent from including ”one more type” in the set Ξ, on the other. If the planner considers to include ”one more type” into the set Ξ, there is a cost saving c, as no relocation takes place, which has to be balanced against the sum of the higher total cost of pollution and the expected increase in rent from including ”one more type”.
If social cost of pollution; D(x) + (1 + m)v(θ – x), is highly convex in x, rent extraction is accomplished by inducing a ”large” reduction in pollution abatement or inducing a substantial increase in pollution. In that case it seems likely that it will be socially desirable to exclude types in a nondegenerate interval $(\hat{x},\overline{q}\,]$. On the other hand, if c is high and slowly declining, with m small and α being close to one, then it is expected that full participation should be wanted even under incomplete information. We therefore have, given that w is strictly concave in ξ:

$$\hat{x} \in (\underline{q},\overline{q}) \text{ iff } c(\overline{q}) < v(\overline{q}-\hat{x}(\overline{q})) + \frac{D(\hat{x}(\overline{q}))}{1+m} + \frac{1+m-a}{1+m}\frac{1}{f(\overline{q})}[v'(\overline{q}-\hat{x}(\overline{q})) - c'(\overline{q})]$$

$\hat{x} = \overline{q}$ if the inequality sign above is reversed, and no exclusion

When using that w is strictly concave in ξ, with the cut-off type in the interior of Θ, it can be verified that a smaller domestic ownership share α, which makes γ higher, will expand the set Σ; i.e. more types should be excluded. The main results of this section are summarised in the next proposition:

Proposition 3. *With asymmetric information about primary discharges, q, with the outside option profile R(q) being increasing in q, and for some given domestic ownership share* a*, the second-best optimal allocation* $\{\hat{x}(q), \hat{U}(q), \hat{x}\}$ *is characterised by: For any type being induced to stay, i.e. for any* q Î $[\underline{q}, \hat{x}]$*, net emissions, rent, along with the marginal type* $\hat{x} \in (\underline{q}, \bar{q}]$*, as well as expected welfare, will obey:*

$$\text{(14-i)} \qquad (1+m)v'(q-\hat{x}(q)) - D'(\hat{x}(q)) + g\,\frac{F(q)}{f(q)}\,v''(q-\hat{x}(q)) = 0$$

$$\text{(14-ii)} \qquad \hat{U}(q) = R(\hat{x}) + \int_{q}^{\hat{x}} v'(\tilde{q} - \hat{x}(\tilde{q}))\,d\tilde{q}\ ,\ \textit{with}\ \hat{U}(q) = R(q), \forall q \in (\hat{x}, \bar{q}\,]$$

$$\text{(14-iii)} \qquad c(\hat{x}) - v(\hat{x} - \hat{x}(\hat{x})) - \frac{D(\hat{x}(\hat{x}))}{1+m} - \frac{1+m-a}{1+m}\,\frac{F(\hat{x})}{f(\hat{x})}[v'(\hat{x} - \hat{x}(\hat{x})) - c'(\hat{x})] \geq 0$$

$$\text{(14-iv)} \quad EW = \int_{\underline{q}}^{\hat{x}} [S(q, \hat{x}(q)) - g\,\frac{F(q)}{f(q)}\,v'(q - \hat{x}(q))]\,f(q)\,dq - gR(\hat{x})F(\hat{x}) + a\int_{\hat{x}}^{\bar{q}} R(q)\,f(q)\,dq$$

We also have the following result relating net emissions and participation to foreign ownership:

Corollary 2. *A higher foreign ownership share will induce the participating types of the industry to undertake less pollution abatement (more overpollution) as compared to first best, but the set of types that will be excluded, S, will increase.*

The solution in proposition 3 can be implemented by a non-linear Pigovian tax t(x), which can be derived from (14-i,iii). Due to our assumptions, $\hat{x}(q)$ will be strictly increasing in θ for any $\theta \in \Xi$. We can then consider its inverse $q(\hat{x})$, which is also strictly increasing. Suppose that some of the least efficient types are induced to leave, with $\hat{x} < \bar{q}$. Let $\hat{x}(\underline{q}) = \underline{x}$ and $\hat{x}(\hat{x}) = \bar{x}$. The pollution tax as specified in (15) will then implement the second-best optimum

$$\text{(15)} \quad t(x) = \frac{1}{1+m}\{D(x) + g\int_{x}^{\bar{x}} f(y)v''(q(y)-y)dy + gf(\bar{x})\,[\,v'(q(\bar{x})-\bar{x}) + R'(q(\bar{x}))\,]\}$$

We have defined $f(y) \equiv \frac{F(q(y))}{f(q(y))}$, which is increasing in y, according to MHR, with $f(\underline{x}) = 0$. Because the marginal type $\hat{x}$ is left with a rent exactly equal to its outside option, $U(\hat{x}) \equiv u(\hat{x}, \hat{x}(\hat{x})) = \pi^0 - v(\hat{x} - \hat{x}(\hat{x})) - t(\hat{x}(\hat{x})) = R(\hat{x}) = p^0 - c(\hat{x})$, we can rewrite the tax function in (15) to become

$$\text{(15)'} \qquad t(x) = \frac{D(x)}{1+m} + \frac{g}{1+m}\int_{x}^{\bar{x}} f(y)v''(q(y)-y)dy + t_0 \;\equiv \frac{D(x)}{1+m} + \frac{g}{1+m}h(x,\bar{x}) + t_0$$

where $t_0 = c(\hat{x}) - (\frac{D(\hat{x}(\hat{x}))}{1+m} + v(\hat{x} - \hat{x}(\hat{x}))) > 0$, is the difference between the relocation cost for the marginal type and sum of cost of pollution (privately valued) and abatement cost for this type. The sign of t_0 follows directly if $\hat{x} \in (\underline{q}, \bar{q})$.

The function $h(x, \bar{x})$, which is the integral term in (15)', is a correction term which is imposed so as to provide correct incentives for the industry when deciding on the amount of pollution abatement. This term captures the expected gain some type $\theta \in [\underline{q}, \hat{x})$ would have achieved by misrepresenting its true type (by taking advantage of its superior technology). Because rent has a social cost, this cost is internalised in the tax function, and will therefore be borne by the industry. It is seen that $h(\bar{x}, \bar{x}) = 0$ and $\frac{\partial h(x,\bar{x})}{\partial x} \le 0$, with equality only for $x = \underline{x}$. Hence, the optimal pollution tax for some emission level x, consists of a fixed, type-independent part, t_0, and a variable part, consisting of the sum of two terms: the private valuation of the environmental cost from discharging x, and a term, which is declining in x, capturing the expected increase in rent from higher net emissions. The constant term is fixed so as to get the socially optimal separation of types between staying and leaving.

Faced with this tax scheme, an industry type θ below the marginal type ($\hat{x}$), will choose net emissions (or pollution abatement) so as to minimise $\{v(\theta - x) + t(x)\}$. When being offered this tax scheme, any type with abatement technology in the set $\Xi = [\underline{q},\ \hat{x}]$, will prefer not to relocate, because U^{in} for these types will not fall below the outside option. Cost minimization yields: $v'(q - \hat{x}) = t'(\hat{x}) = \frac{D'(\hat{x})}{1+m} - \frac{g}{1+m}\frac{F(q(\hat{x}))}{f(q(\hat{x}))}v''(q(\hat{x}) - \hat{x})$, which reproduces (14-i). On the other hand, types in the set $\Sigma = (\hat{x}, \bar{q}]$, when facing this tax scheme, will choose the socially optimal decision; i.e. exit, because for these types we have $R(\theta) = \text{Max}\{R(\theta), \max_x[\pi^0 - v(\theta - x) - t(x)]\}$, which makes relocation the privately optimal choice.

In order to extract rent, we have seen that less pollution abatement should be undertaken as compared to what would have been optimal under complete information. This distortion is accomplished by imposing a marginal pollution tax below what would have been imposed under complete information. The marginal pollution tax (in social terms) of the optimal tax scheme, is $(1 + m)t'(x) = D'(x) + \gamma\frac{\partial h(x,\bar{x})}{\partial x} \leq D'(x)$. Hence the marginal price for discharges is below the direct social marginal damage, with equality only for the most efficient type in the set Ξ. The correction term $\gamma\frac{\partial h(x,\bar{x})}{\partial x}$ is seen to be smaller in absolute value, the less distortive is domestic taxation and the more of the industry that is owned by domestic citizens.

4. Conclusions

We have characterised optimal environmental regulation of an exporting industry whose outside option is negatively correlated with abatement efficiency. The main issues have been to see the impact on local pollution as well as participation of foreign ownership and the presence of an increasing outside option. Because outside option is supposed to

be negatively correlated with abatement efficiency, standard techniques can be used, as the dominating incentive for the industry is to overstate the true efficiency. Because rent has a social cost, which is higher the higher is foreign ownership share, rent extraction is accomplished by inducing less pollution abatement as compared to complete information. We have demonstrated that if total cost of pollution is sufficiently convex, exit of a subset of the least efficient types becomes more likely, and even more likely the more of the industry is owned by foreigners. Furthermore, the higher is foreign ownership share, the more important is rent extraction, which calls for more pollution than what would have been realised for a lower foreign ownership share.
A further step in analyzing the relationship between environmental regulation, foreign ownership and outside option will be to allow for positive correlation between efficiency and outside option. This will normally create countervailing incentives, with exclusion of types not necessarily in the upper part of the distribution. As demonstrated by Jullien (op.cit.), the curvature of the outside option-profile will then play an important role both with regard to the direction of allocative distortions and the set of types that should be induced to relocate.

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