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ENVIRONMENTAL REGULATION, ASYMMETRIC INFORMATION AND FOREIGN OWNERSHIP

By
Jon Vislie

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Department of Economics
University of Oslo

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

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ENVIRONMENTAL REGULATION, ASYMMETRIC INFORMATION AND FOREIGN OWNERSHIP

Jon VISLIE[1]

Department of Economics, University of Oslo

P.O.Box 1095, Blindern, N-0317 OSLO, Norway

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

Abstract:

Regulating an export firm (or a homogeneous industry) with private information about emission technology is analysed, when the firm, owned partly by foreigners, has an option to bypass domestic regulation through costly relocation. If the firm chooses to relocate, it will set up a new plant in a region practicing environmental dumping, at a cost that is correlated with emission efficiency, so as to make the firm's reservation utility type-dependent. We characterise the set of optimal contracts offered by the uninformed, domestic government under different ownership structures, when domestic taxation is distortive, and when welfare is the sum of consumers' surplus and the share of the firm's rent accruing to domestic residents. With complete information, ownership has no real effects. When information is incomplete, ownership matters, due to rent extraction, being of greater significance when ownership rights are shifted towards foreigners. Rent extraction is accomplished by offering contracts with lower output and higher net emissions to a subset of the most efficient types (being induced to stay), whereas a subset of the least efficient types should be induced to relocate. A demand for environmental dumping is being induced by the domestic government's concern for national interests. When barriers towards foreign ownership are lowered, and then shifting the distribution of ownership rights in the favour of foreigners, more pollution will be generated for types of the firm that do not exit, whereas a larger fraction of the firm types should be induced to relocate.

Keywords: Asymmetric information, environmental regulation, foreign ownership.

JEL classification: D62, D82, H23, L51

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1. Introduction

It is said that we live in the age of globalisation, featuring e.g., higher capital mobility, more intense international tax competition and fewer restrictions on foreign ownership to firms located in various regions. These changes are expected to have some impact on the economic and political environment of national governments. When unilateral actions taken by a government could have some desired effects in earlier periods, such actions cannot longer be taken without recognising the potential counteractions taken either by affected parties or by other governments so as to leave affected parties with new sets of options. (Attempts at taxing highly mobile factors of production are often met by owners of these factors threatening to move to regions or jurisdictions where more favourable tax rules are offered.) The literature on international tax competition in the field of environmental regulation has focused on various issues within this area. For instance, there is one branch discussing the impact of domestic environmental policy on delocation of plants, within an imperfectly competitive environment and complete information, taking foreign environmental policies as given; see e.g. Markusen et al. (1993), and Motta and Thisse (1994). In another branch, the impact of environmental policies on plant location is analysed within a multi-country, multi-firm, complete information framework where governments play a non-cooperative game with domestic environmental instruments (pollution taxes or standards) as strategic variables; see e.g. Markusen et al. (1995), Rauscher (1995) and Hoel (1997). In a broad sense these papers try to reach some qualitative conclusions as to whether strategic uncertainty and interjurisdictional tax competition will lead to a too lax or too strict domestic environmental policy. Another line of reasearch has focused on the impact of incomplete or asymmetric information on the design of environmental policy, see e.g. Roberts and Spence (1976), Kwerel (1977), Baron (1985), Spulber (1988), Laffont (1994), van Egteren (1996), Lewis (1996), and Mansouri and Youssef (2000). The main insight from this literature is that privately informed agents will have to be offered a rent for revealing their private information. Leaving rent is normally socially costly; hence the policy designer or regulator will find it desirable to extract these rents, which will be accomplished by imposing some allocative distortions. The direction of these distortions, especially how domestic pollution should be distorted relative to complete information, will depend on how pollution and rent interact.

The purpose of the present paper is to bring together elements from these lines of reasearch. We want to analyse environmental regulation under incomplete information within the following context: There is one firm located in some country. This firm is harming the local environment through its pollution, which is a by-product of the production of some commodity, produced solely for export. We assume that the firm is owned (partly) by foreigners, and has an option to bypass domestic regulation by closing down domestic plants and instead set up a new plant within a jurisdiction with no environmental regulation. There is no explicit interjurisdictional tax competition, as we take the loose environmental policy abroad as given. The main issue is to analyse the impact of foreign ownership to the polluting firm on domestic environmental policy under incomplete information and an exit or relocation option. The answer will of course depend on the domestic government's objective function. In the present framework we assume that the government only takes national welfare into account, by maximising the sum of domestic consumers' surplus (or taxpayers' surplus), net of environmental damage, and rent accruing to domestic owners of the firm. In that case, the weight put on rent will vary with foreign ownership share. (Laffont (1996) has, within a political economy model of regulation, demonstrated that ownership will have a similar impact on the regulation of a natural monopoly. The role of ownership of polluting firms is to a large extent ignored in the literature. However, Hoel (op.cit.) is an exception. He shows, within a setting different from the one here, that distribution of ownership will have some impact on domestic environmental policy. One implication of his model that is relevant here, is that the socially optimal emission tax rate (under complete information) will be higher - inducing lower emissions - the larger is the share of profits that accrue to residents outside the common jurisdiction. In this paper we get a result which partly goes in the opposite direction: higher foreign ownership share and incomplete infomation might lead to higher emissions for the firm types that do not relocate, but induced relocation becomes more likely.)

To get some insight into the complex interaction between domestic environmental regulation, incomplete information, the role of ownership and the issue of relocation, we set up a simple model, having one exporting firm located in a home country. Along with output, gross emissions (primary discharges) are produced in fixed proportions to output, with the factor of proportionality taken as a measure of the effectiveness of the installed emission technology, which is private information to the firm. Even though we assume a fixed relationship between primary discharges and output, this relationship can be modified as the firm is able to undertake non-verifiable pollution abatement. The government wants to impose policy rules so as to get the firm to take account of the costs of pollution. However, the firm's private information impedes the regulator from evaluating correctly the costs and benefits from continued production at home. In addition, the domestic government has to take into account the firm's option to relocate by incurring a set-up cost that is higher the more effective is the firm's emission technology. (This assumption is justified below.) Hence, the firm's reservation utility or participation constraint will be type-dependent. (See e.g. Laffont and Tirole (1990), Maggi and Rodríguez-Clare (1995), Curien et al. (1998) and Jullien (2000) for more on principal-agent models with type-dependent reservation utility.) The distribution of ownership rights between foreign and own residents is taken as an exogenous parameter. Because the government is concerned only about own residents' welfare, the weight put on rent in the welfare function is lower the higher is foreign ownership share. Under complete information, we show in section 2 that under if no relocation is socially desirable, ownership has no impact on the policy rules, only maximal domestic welfare will be affected negatively by foreigners' ownership share. On the other hand, we show in section 3 that under incomplete information, distribution of ownership rights will have an impact both on the policy rules, the level of expected welfare, as well as those types of the firm that should be induced to relocate. This is a robust result in the sense that it does not hinge on domestic taxation being distortionary. In section 4 we consider how the environmental policy and expected pollution will be affected by a redistribution of ownership rights. If foreign ownership share increases, rent extraction becomes more important, implying that relocation becomes more likely with net emissions being higher for those types of the firm that should be induced to stay. Hence the impact on expected local pollution from a higher foreign ownership share is ambiguous. Section 5 concludes.

2. The model

We consider a rather simple model consisting of one polluting firm, located in a ”home” country, while selling its output solely in a foreign market. By assumption, the firm is owned partly by domestic residents, with an exogenous ownership share, denoted $\alpha \in [0, 1]$. Net revenue from exporting y units of the output is given by $\pi(y)$, which by assumption is strictly concave, with $\pi(0) = 0$, and a unique maximum for $\tilde{y} > 0$. Along with output, an amount of primary discharges (”gross emission”) θy is produced, where θ is a one-dimensional technology parameter, known only by the firm. The smaller value θ takes the cleaner is the emission technology, as the level of emissions (prior to abatement) per unit output is smaller. (Later we consider a closed type space $\Theta = [\underline{\theta}, \overline{\theta}]$.)

Net emissions (x) will be equal to the difference between the amount of primary discharges or gross pollution, θy, and pollution abatement, $A = \theta y - x$. Although we assume a fixed type-dependent relationship between the level of output and primary discharges, the relationship between output and the level of externality (net emissions or pollution) can be modified through costly (and unverifiable) pollution abatement. Let the (unverifiable) cost of abatement be v(A); which is thrice continuously differentiable, strictly increasing in A for any A > 0, with $v(0) = v'(0) = 0$, and strictly convex for any $A \geq 0$. (In addition we assume $v'''(A) \geq 0$.)

Social damage or domestic environmental cost caused by net emissions is D(x). The damage is purely local. D(x) is assumed to be twice continuously differentiable, strictly increasing for any x > 0, with $D(0) = D'(0) = 0$, and strictly convex for any $x \geq 0$.

As will be obvious, the firm should be made responsible for its damage on the local environment. However, if the owners of the firm should find the domestic regulation too unfavourable, the firm might either shut down or, if possible, relocate. To capture the relocation issue, we have to specify the firm’s options. Suppose that if the firm relocates, it will move to a region with no environmental regulation, and will here be able to capture the maximal profit $\pi(\tilde{y})$, by incurring some exit or relocation cost. For ease of exposition we let exit cost depend on the type parameter θ. (We then avoid technical problems related to a multi-dimensional type space, as being analysed by Armstrong (1999) and Armstrong and Rochet (1999).) Next, we suppose that the exit cost is negatively correlated with the type parameter θ. This assumption can be justified by thinking of a clean firm (one with a low θ) makes intensively use of specific factors not required by a firm with a dirty technology. Hence, the cost of switching location is therefore non-increasing in θ. In addition the exit cost $c(\theta)$ is twice continuously differentiable, with $c'(\theta) \leq 0$. (Note that if we should have imposed $c'(\theta) > 0$, then we would face some additional technical problems, due to countervailing incentives, as analysed by Lewis and Sappington (1989), Maggi and Rodríguez-Clare (op.cit.) and Jullien (op.cit.). Our assumption about the set-up cost helps reducing the equilibrium set, and the exclusion issue can be analysed by using standard techniques.)

When complying with domestic environmental regulation and taxation, the firm's rent, when producing y units of the final output for export, is

$$U^{in} = \pi(y) - v(\theta y - x) - T \quad (1)$$

with T being taxes paid to the domestic government. In this case, the consumers' or tax-payers' surplus will consist of the social value of tax revenue minus the social cost due to local pollution D(x). Because we rule out lump-sum taxation, any tax revenue collected from the firm has a social value equal to (1 + m)T, where m is the marginal cost of public funds. Hence, in this case consumers' surplus is

$$CS^{in} = (1+m)T - D(x) \quad (2)$$

If on the other hand the firm relocates, it will capture a rent, net of exit costs

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

but now the domestic government has no power to tax the firm. (Note that the firm's reservation utility $R(\tilde{y}, \theta)$ is type-dependent and non-decreasing in θ by assumption.) However, there is a gain from relocation because the local cost of pollution will vanish altogether; hence $CS^{out} = 0$.

Let the welfare measure be the sum of consumers' surplus and the domestic share of the firm's rent; hence we define $W = CS + \alpha U$. Furthermore, define the "tax-adjusted" welfare weight put on rent as $\gamma := 1 + m - \alpha > 0$.

When information is complete, maximal welfare, denoted W^*, is determined as the solution to the following problem

$$(4) \qquad W^* = max\left\{\alpha R(\tilde{y},\theta),\ max_{x,y,U}\left[S(\theta,x,y) - \gamma U \middle| U \geq R(\tilde{y},\theta)\right]\right\}$$

when we have used that $S(\theta,x,y) = (1+m)[\pi(y) - v(\theta y - x)] - D(x)$ is the social surplus generated by the firm's domestic activity. If the firm should relocate, welfare is equal to the domestic share of rent captured abroad, but if the firm continues its operations at home, welfare is equal to the maximised net surplus, with the firm being offered a rent at least as high as its outside option. (In the optimal solution this constraint will be binding, because leaving a too high rent will reduce welfare.)

Let us now make an assumption that makes "no relocation" part of the optimal solution under complete information:

There exists a pair (x^*, y^*), with $x^* \in (0, \theta y^*)$ and $y^* \in (y^c, \tilde{y})$ so that for any $\theta \in \Theta$, $W^*(\theta) = S(\theta, x^*, y^*) - \gamma R(\tilde{y},\theta) > \alpha R(\tilde{y},\theta)$, or equivalently,

$$(5) \qquad c(\theta) - v(\theta y^* - x^*) - \frac{D(x^*)}{1+m} > \pi(\tilde{y}) - \pi(y^*)$$

This requirement says that there exist some net emission and some output level so that social welfare from having the firm operating at home is higher than welfare if the firm should relocate. (We have also restricted first-best output to be in the interval $(y^c, \tilde{y})$, where the lower bound y^c solves $\Pi'(y^c) = 0$, where $\Pi(y) := y\pi'(y)$ is strictly concave and $\Pi(y) \geq 0$ for any $y \in [0, \tilde{y}]$. Hence, by assumption we have $\Pi'(y^*) = \pi'(y^*) + y^*\pi''(y^*) < 0$.)

Because $S(\theta, x, y)$ is strictly concave in (x, y), it is easy to see that under complete information, we have the following result:

Proposition 1

Given our assumptions, first-best allocation (x^*, y^*, U^*, W^*) is characterized by:

$$(6\text{-}i) \qquad -D'(x^*) + (1+m)v'(\theta y^* - x^*) = 0$$

$$(6\text{-}ii) \qquad \pi'(y^*) - \theta v'(\theta y^* - x^*) = 0$$

$$(6\text{-}iii) \qquad U^* = R(\tilde{y}, \theta)$$

$$(6\text{-}iv) \qquad W^*(\theta) = S(\theta, x^*, y^*) - \gamma R(\tilde{y}, \theta)$$

Optimal net emissions, x^*, should equate marginal damage to social marginal cost of abatement (i.e. cost efficiency), whereas output exported y^*, which is below the unregulated level $\tilde{y}$, should maximise net profits; i.e. revenue extraction. (Given our assumptions, it can easily be verified that the first-best emission profile $x^*(\theta)$ is strictly increasing in θ, whereas first-best output $y^*(\theta)$ is strictly declining in θ. (From (6i-ii) we get $\frac{dy^*(\theta)}{d\theta} = \frac{-(1+m)}{\Delta}\left[v'(1+m)v'' + D''(v' + \theta y v'')\right] < 0$ and $\frac{dx^*(\theta)}{d\theta} = \frac{-(1+m)}{\Delta}\left[\pi' + y\pi''\right] > 0$. These signs follow directly from our assumptions with $\Delta = \left[S_{xx} S_{yy} - S_{xy}^2\right] = (1+m)\left[D''(\theta^2 v'' - \pi'') - v''(1+m)\pi''\right] > 0$ because S is strictly concave in (x, y).)

No rent above the outside option should be left to the firm, saying that profits above the reservation level should be taxed away. But when the domestic regulator or government has the power to tax away any rent in excess of the outside option, first-best allocation (x^*, y^*) is unaffected by ownership structure, whereas maximal social welfare will be higher the higher is the domestic ownership share α. (We also note that the more distortive is domestic taxation, so that the cost of raising tax revenues, m, becomes higher, will make both x^* and y^* higher.) Maximal social welfare under complete information $W^*(\theta)$, which by assumption is higher when the firm is complying with domestic regulation rather than moving abroad, will vary with the type of the firm. Due to our assumption about the exit cost, $W^*(\theta)$ will be declining in θ, as seen from

$$(7)\quad \frac{\partial W^*(\theta)}{\partial\theta} = S_\theta(\theta, x^*, y^*) - \gamma\frac{\partial R(\tilde{y},\theta)}{\partial\theta} = -(1+m)y^* v'(\theta y^* - x^*) + \gamma c'(\theta)$$

This feature of the solution will have the following implication: When leaving the assumption of complete information, we know that some types of the firm will have to be offered a rent as a compensation for revealing their true type. To reduce this incentive, the regulator will normally distort (x, y) away from their first-best values so as to reduce the firm's scope for profitable misrepresentation, implying that welfare is reduced below W^* for any type of the firm. For that reason, social welfare might be higher by inducing some of the dirty types of the firm to relocate. (Jebjerg and Lando (1997) analyse the possibility of shutdown of heavy polluters, within a model close to the present one, but with fixed output and no outside option.)

The first-best solution can be implemented in various ways under complete information; one is through a two-part emission tax, as given by

$t(x) = \dfrac{D(x)}{1+m} + t_0$, where the fixed part is type-dependent obeying

$t_0 = \pi(y^*) - v(\theta y^* - x^*) - \dfrac{D(x^*)}{1+m} - R(\tilde{y},\theta) = \dfrac{S(\theta, x^*, y^*)}{1+m} - R(\tilde{y},\theta)$. When facing this tax schedule, the firm will produce and pollute according to (6i-ii) and obtain a rent exactly equal to the outside option.

Let us have this first-best solution in mind as a benchmark when turning to asymmetric information about the emission technology. Our main focus is to see how environmental regulation will be affected by private information about the emission technology, as given by the parameter θ, as well as how regulation is affected by different ownerhip regimes, when the firm has an outside option as given in (3).

3. Optimal regulation under asymmetric information

Consider now a more realistic situation where the firm is privately informed about the technology parameter θ. To deal with this problem, we make use of recent developments in the theory of incentive regulation, which, according to several authors seems to be particularly appropriate. For instance, Lewis (op.cit. p.820) says: "The application of incentive regulation to environmental protection is particularly appropriate because the regulator is often quite uninformed about the private benefits citizens enjoy from improved environmental conditions and the costs producers and consumers bear to reduce pollution."

The new economics of regulation have offered insight into the issue of how to regulate privately informed firms. To see what kind of modification that is required to cope with private information, let us first see what the outcome would be if the privately informed firm were to be offered the tax schedule implementing the first-best solution in Proposition 1. It should be rather obvious that any type of the firm in that case would pretend to have the "worst" technology ($\bar{\theta}$). If a θ-firm, $\theta \in [\underline{\theta}, \bar{\theta})$, should claim to have the least efficient emission technology and then undertake pollution abatement so as to emit $x^*(\bar{\theta})$, the firm will obtain a rent as given by

$$(8) \qquad u(\theta,\bar{\theta}) = Max_y \left[\pi(y) - v(\theta y - x^*(\bar{\theta}))\right] - \frac{D(x^*(\bar{\theta}))}{1+m} - t_0(\bar{\theta})$$

Let $V(\theta,x) = Max_y \left[\pi(y) - v(\theta y - x)\right]$, so that $V_\theta(\theta,x) = -yv'(\theta y - x)$. Then we can rewrite (8), when inserting for the fixed fee $t_0(\bar{\theta})$, to get:

$$(8)' \qquad \begin{aligned} u(\theta,\bar{\theta}) &= R(\tilde{y},\bar{\theta}) - \left[V(\bar{\theta},x^*(\bar{\theta})) - V(\theta,x^*(\bar{\theta}))\right] = R(\tilde{y},\bar{\theta}) - \int_\theta^{\bar{\theta}} V_z(z,\bar{x})dz \\ &> R(\tilde{y},\bar{\theta}) = max_{\theta\in\Theta}\ R(\tilde{y},\theta) \quad for\ \bar{x} := x^*(\bar{\theta}) \end{aligned}$$

Hence: The first-best policy of Proposition 1 cannot be implemented through a two-part emission tax when the firm has private information about its emission technology. If the government should impose the emission tax schedule t(x), expected net emissions will become too high and expected rent given away will be too generous, as this tax scheme will not lead to separation among types. We therefore have to look for an incentive compatible mechanism, i.e. one that motivates the firm to reveal its private information.

To see the full impact of private information, we'll assume that output, as well as net emissions and taxes paid by the firm can be verified, and written into a regulatory contract. However, neither abatement nor abatement cost (say, due to accounting manipulation) can be verified. Therefore, the regulatory problem becomes very similar to multiproduct regulation as analysed in chapter 3 by Laffont and Tirole (1993). (One might dispute the assumption that both output and net emissions can be verified. What can be made part of a contract will vary from case to case; sometimes only the use of externality-generating inputs can be verified, while in others only net emissions can be verified. However, one justification for our assumption is that we then get a model being ”very close” to our benchmark model, making it possible to see the impact of asymmetric information alone. In Vislie (2001), it is assumed that only net emissions can be verified, and it is shown that the distortions in net emissions, relative to first best, can go either way, depending on the firm's market power in the foreign market.) The main purpose here is to analyse whether foreign ownership will have any impact on optimal regulation under incomplete information, when the firm has an option to relocate. To get some insight into this issue, we restrict attention to one-period regulation, which is of course a bit unrealistic. However, the insight obtained might be of some help when turning to more complex cases.
We have by assumption a single government agency who is delegated the authority to regulate the firm's output and net emissions. The regulator does not know the type of the firm, but has prior beliefs, which are common knowledge, given by the strictly increasing and twice continuously differentiable cumulative distribution function $F(\theta)$, so that the density $f(\theta)$ is strictly positive on the fixed support $\Theta = [\underline{\theta}, \overline{\theta}]$. The distribution is assumed to satisfy the ”monotone hazard rate property” so that $\frac{F(\theta)}{f(\theta)}$ is non-decreasing in θ, $\forall\theta\in\Theta$. The regulator knows that the firm will take advantage of its private information so as to capture a

socially costly informational rent. To counteract the incentive for misrepresenting type, the regulator will, as is now well known, design contract rules that will make it socially desirable to deviate from ordinary allocative efficiency or trade off rent extraction and allocative inefficiencies. The regulator's problem is then to choose in the class of truth-telling mechanisms, as well as types of the firm that should be induced to relocate, the set of contracts that will maximise expected welfare. (In Appendix A, we have derived first- and second-order conditions ensuring that revealing information truthfully is optimal for the firm.)

Because of the properties of the first-best solution, as stated in the two conditions (5) and (7), we noted that if some types of the firm should be induced to relocate, these types are expected to be in the upper part of the set Θ. Hence, a priori we can divide Θ into two disjoint sets; Ξ and Σ, where Ξ is the set of firm types that will continue operations at home, whereas Σ is the set of types that will be induced to relocate. When deriving the optimal solution, we take advantage of this a priori information. Therefore, the upper bound (or "cut-off"-type) in the set $\Xi = [\underline{\theta}, \xi] \subseteq \Theta$ is to be determined as part of the problem.

The regulator's problem can therefore be stated as choosing the set of participating types (Ξ), their net emissions as well as output exported, so as to maximise expected welfare subject to the incentive constraints and the type-dependent participation constraint:

[RP]

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

so that $\forall \theta \in \Xi = [\underline{\theta}, \xi]$, and $\xi \in \Theta$

$$\dot{U}(\theta) = -y(\theta) \cdot v'(\theta y(\theta) - x(\theta)) \qquad (IC_1)$$

$$y(\theta) \cdot v'' \cdot \frac{dx(\theta)}{d\theta} - \left[v' + \theta y(\theta) v'' \right] \cdot \frac{dy(\theta)}{d\theta} \geq 0 \qquad (IC_2)$$

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

$$\text{with } S(\theta, x, y) = (1+m)\left[\pi(y) - v(\theta y - x) \right] - D(x)$$

(The first integral in the objective function is the expected net surplus generated for those types that do not relocate, whereas the second integral is the domestic share of the expected value of the type-dependent outside option captured by types that relocate.) The solution to this problem is found in Appendix B; here we just state the main result, when assuming the optimal cut-off type being in the interior of Θ:

Proposition 2

Optimal regulation under incomplete information, as given by $\left\{x^0(\theta), y^0(\theta), U^0(\theta), \xi^0\right\}$ *is characterised by:*

$$(9-i)\quad -D'(x^0)+(1+m)v'(\theta y^0-x^0)+(1+m-\alpha)\frac{F(\theta)}{f(\theta)}y^0 v''(\theta y^0-x^0)=0$$

$$(9-ii)\quad \pi'(y^0)-\theta v'(\theta y^0-x^0)-\frac{1+m-\alpha}{1+m}\frac{F(\theta)}{f(\theta)}\left[v'(\theta y^0-x^0)+\theta y^0 v''(\theta y^0-x^0)\right]=0$$

$$(9-iii)\quad U^0(\theta)=R(\tilde{y},\xi^0)+\int_{\theta}^{\xi^0} y^0(\tilde{\theta})v'(\tilde{\theta}y^0(\tilde{\theta})-x^0(\tilde{\theta}))d\tilde{\theta}$$

$$(9-iv)\quad W^0(\xi^0)f(\xi^0)-(1+m-\alpha)F(\xi^0)\cdot\left[y^0(\xi^0)v'(\xi^0 y^0(\xi^0)-x^0(\xi^0))-c'(\xi^0)\right]=0$$

for $\xi^0\in(\underline{\theta},\overline{\theta})$*, where* $W^0(\xi^0):=S(\xi^0,x^0(\xi^0),y^0(\xi^0))-(1+m)R(\tilde{y},\xi^0)$ *and S defined above.*

With distortive domestic taxation, and a fixed foreign ownership share, the conditions (9i-ii) reflect the familiar trade-off between allocative inefficiencies and rent extraction. To reduce rent for types in Ξ, the regulator will induce higher net emissions (for any given output level) and lower output (for any fixed net emission), less efficient than the $\underline{\theta}-$type, relative to complete information. This seems reasonable, because these distortions will make it less profitable for a clean firm to pretend to have a more dirty technology. (The slope of the rent function, $-\dot{U}(\theta)=yv'(\theta y-x)$, is made smaller either by lowering output y and/or by inducing less pollution abatement $A = \theta y - x$, relative to complete information. When less output is produced and sold abroad, domestic pollution is automatically reduced if abatement were kept unchanged. However, in order to reduce rent, not only output y should be reduced, but abatement $A^0 = \theta y^0 - x^0$ as well.

Condition (9-i) provides a second-best optimality rule for net emissions (or induced pollution abatement). Social marginal benefit from pollution abatement should be equal to the modified social marginal cost of abatement, when account is taken for the marginal impact of abatement on the social value of inframarginal rent. (9-ii) provides the optimality rule for output exported. For any type of the firm, output exported should balance the social value of marginal (net) profit, $\pi'(y) - \theta v'(\theta y - x)$, and the marginal impact of output on the social value of inframarginal rent.

These distortions will have an impact only for those types of the firm that should be induced to stay. Because the efficient types of the firm have to be offered a rent for revealing their private information, above what they could have achieved by bypassing domestic regulation through relocation, it might be socially desirable to get some of the inefficient types to relocate. As output and pollution now will deviate from those under complete information, $W^0(\theta) < W^*(\theta)$ for any $\theta \in \Xi$. Furthermore, due to private information, any firm with type $\theta \in [\underline{\theta}, \xi^0)$ will earn a rent above the minimal rent offered under complete information $R(\tilde{y}, \theta)$. Hence, even though we assumed that $S(\theta, x^*(\theta), y^*(\theta)) - \gamma R(\tilde{y}, \theta) > \alpha R(\tilde{y}, \theta)$ for any $\theta \in \Theta$ under complete information, making full participation part of the social optimum, this property will normally not carry over to incomplete information.

The condition (9-iv) gives a precise condition for the partition of Θ into the two sets Ξ and Σ: On expanding the set Ξ from $[\underline{\theta}, \xi]$ to $[\underline{\theta}, \xi + \Delta\xi]$, we include $f(\xi)\Delta\xi$ more firms in Ξ. (Note that pollution and output will be adjusted according to (9i-ii); hence the marginal impact of these adjustments will vanish.) The corresponding increase in net surplus is then to be given as $[S(\xi, x^0(\xi), y^0(\xi)) - \gamma R(\tilde{y}, \xi)] f(\xi)\Delta\xi$, which has to be balanced against the cost of increasing the participation set Ξ. First, there is a direct (expected) loss because we give up the domestic share of net profits these $f(\xi)\Delta\xi$ firms could make from relocating, as given by $\alpha R(\tilde{y}, \xi) f(\xi)\Delta\xi$. In addition, rent to inframarginal firms, in number $F(\xi)$, has to be increased, both directly and indirectly. The direct effect follows from the ordinary increase in rent for all inframarginal types when increasing the set Ξ , for a fixed end-point constraint on U, whereas the indirect effect follows from the increasing outside option. (The marginal type will therefore require a higher rent.) Hence, rent will increase by $F(\xi)\left[-\dot{U}(\xi)+\frac{\partial R(\tilde{y},\xi)}{\partial \xi}\right]\Delta\xi$. The social cost of the additional rent is therefore $\gamma F(\xi)\left[-\dot{U}(\xi)-c'(\xi)\right]\Delta\xi$. For the marginal type, ξ^0 in the interior of Θ , the marginal net surplus is equal to marginal cost, as shown in (9-iv).

Before discussing how increased foreign ownership might affect optimal regulation under incomplete information, let us make some remarks about the solution in Proposition 2.

Remark 1

Foreign ownership matters for optimal regulation under incomplete information. Even if domestic taxation is non-distortive (m = 0), foreign ownership will make some distortions from first-best efficiency, socially desirable.

(A similar result, but within a model with a different emission technology, has been derived by Baron (1985). In his model the domestic firm's profit is given a weight $\alpha \leq 1$ in the social welfare function, when taxation is non-distortionary. There will be no distortions if $\alpha = 1$, as will also be the case in the present model with m = 0 and $\alpha = 1$. On the other hand, if $\alpha < 1$, Baron shows that rent extraction is an issue, and distortions should be induced. This was also seen to be the case within the present model, as noted in Remark 1.)

Remark 2

Expected domestic damage, relative to complete information, will under incomplete information and foreign ownership either increase (if the set Σ is empty or "almost" empty) or decrease (if a the mass of firms being induced to move is large). A closer look at (9-iv) will show that the faster the outside option is increasing and/or the higher is foreign ownership share, the larger is the fraction of firms that will relocate.

Environmental regulation under incomplete information and foreign ownership, will (sometimes) make it desirable to get the most dirty types to relocate, while at the same time distort net emissions upwards for the remaining types. Hence what we can say is that expected domestic pollution (and hence expected domestic damage), conditional on output, can go either way, as compared to complete information. What can be said, although this is not important as long as we restrict pollution to be domestic or local, is that *total expected net emissions will increase*, because the firm types that move will produce more, as $\tilde{y} > y^* > y^0$, and will not be forced to undertake any pollution abatement. (The expected increase in emissions might cause a smaller increase in environmental damage in the new region than what might be the case in the "home country".)

Remark 3

If the optimal solution under incomplete information can be implemented by a non-linear tax T(x, y), the Pigovian part of that tax should be reduced below what would be the case under complete information, whereas the output tax should be increased. The marginal pollution tax will for any (x, y), be lower the higher is foreign ownership share, but the marginal tax on output will, for any (x, y), be higher the higher is foreign ownership share $(1-\alpha)$*; cf. (10).*

This remark is related to implementation of the second-best solution. This problem is not an easy one within a multi-output context, as summarised by Lewis (op.cit. p 830), who says: "Unfortunately, though, stringent monotonicity and curvature conditions are required for the implementation of this [optimal] scheme. And even if the procedure is implementable, it requires the regulator to design a different set of prices and taxes for each conceivable type…". In their Proposition 3.2, Laffont & Tirole (op.cit.) offer sufficient conditions for when an optimal multi-output regulatory mechanism can be implemented through a menu of linear contracts. These conditions are not satisfied in the present model. However, rather than looking at implementation through a menu of linear contracts, we briefly consider how the optimal solution might be implemented by using "ordinary" tax instruments, following Laffont (1994). We might impose a combined non-linear pollution-output tax $T(x,y)$, derived from using the information embodied in (9i-

iv) in Proposition 2. First, this tax schedule has to obey a boundary condition so that the marginal (or the cut-off) type, ξ^0, earns a rent exactly equal to its outside option. Secondly, the tax scheme should be designed so that no type in the set Σ will find it profitable to stick to its present location. Third, if the regulator offers a tax scheme with a marginal pollution (or Pigovian) tax and a marginal output tax, both personalised, of the following kind,

$$(10) \qquad \begin{cases} \dfrac{\partial T(x,y)}{\partial x} = \dfrac{D'(x)}{1+m} - \dfrac{1+m-\alpha}{1+m} \cdot \dfrac{F(\theta)}{f(\theta)} \cdot yv''(\theta y - x) \\ \dfrac{\partial T(x,y)}{\partial y} = \dfrac{1+m-\alpha}{1+m} \cdot \dfrac{F(\theta)}{f(\theta)} \cdot \dfrac{d}{dy}\left[y \cdot v'(\theta y - x)\right] \end{cases}$$

any firm in the set Ξ will on maximising after-tax rent, in principle (if monotonicity and curvature conditions are satisfied, so that T(x,y) is convex), be motivated to take actions in accordance with the second-best allocation in Proposition 2.

4. The impact of increased foreign ownership

We have seen that under incomplete information ownership matters. As has been noted in section 2, foreign ownership has an impact only on domestic welfare, not on pollution and output, when information is complete. However, with incomplete information, we saw in section 3 that foreign ownership will have an impact not only on expected welfare, but also on net emissions and output. The reason is that under incomplete information, rent extraction becomes important with the cost of giving away rent being higher the higher is foreign ownership share $(1-\alpha)$.

In this section we examine briefly the impact on environmental regulation from relaxing any restrictions on foreign ownership to firms. The reason for taking up this problem is the popular view that we now live in the age of globalisation, with high capital mobility and fewer restrictions on foreign ownership. Hence, we expect that this kind of deregulation will have some real effects. As long as the national government puts weight on profits or rents accruing to own residents, a change in ownership structure, modelled as a declining α, will have an impact on the policy rules, and hence on resource allocation, implicitly determined by the conditions in Proposition 2.

As demonstrated in Appendix C, the cut-off type will have a more efficient emission technology the higher is $(1-\alpha)$. Hence, the likelihood for relocation is increasing with foreign ownership, or put another way, interjurisdictional firm mobility will increase. Furthermore, when $(1-\alpha)$ increases, the cost of leaving rent (as measured by the parameter γ) will increase as well. To mitigate this effect, the government will be more concerned about rent extraction by getting the firm to increase net emissions (through a lower marginal pollution tax) and reduce output, for any $\theta \in \left(\underline{\theta}, \xi^0\right]$. (Due to these changes in x and y, rent will be lowered for any type in the participation set; see Appendix C for details.) We can therefore conclude with:

Proposition 3

Under incomplete information, increased foreign ownership makes rent extraction more important. The optimal response by the domestic government to increased foreign ownership is to induce a reduction in the participation set (Ξ), a reduction in output exported and an increase in net emissions.

If foreigners, due to some global deregulation, can more easily buy ownership rights to locally polluting firms, we have found that environmental policy will be changed, with an ambiguous impact on domestic environment. There are two opposing effects due to lower barriers to foreign ownership: First, because rent extraction becomes more important, more pollution should be induced for firm types not being induced to relocate. Secondly, for fixed net emissions, the fraction of firm types that should be induced to stick to the original location should be reduced, because the cost of leaving rent gets higher. This effect will push towards reduced expected local damage, whereas the first one pushes towards higher local pollution. Hence, the impact on expected local pollution is ambiguous within the present framework.

Another implication of “lower barriers to foreign ownership” (or higher capital mobility in a broad sense) is the unintentional impact on interjurisdictional firm mobility. When autonomous, but less informed, governments, pursue their goal of maximising expected national welfare through a proper design of domestic environmental policy, they will demand the services offered by countries practicing environmental dumping. Hence, when some country is pursuing a strict environmental policy, so as to meet its national goal, the fact that some other country is practicing environmental dumping so as to attract foreign investments might be mutually beneficial.

5. Conclusion

We have analysed a standard model for regulating an exporting firm producing a negative local externality under incomplete information. Not surprisingly we have seen that incomplete information and distortive domestic taxation will make some distortions from first best socially desirable, because rent extraction now is an issue. In addition to demonstrating the optimal trade-off between allocative inefficiencies and rent extraction, one goal of the paper has been to analyse the impact on second-best optimality of changing the ownership regime, by relaxing barriers to foreign ownership control. (This is one among many features of globalisation.) Because informational rent to domestic owners enters the welfare function, an increasing share of foreign owners will increase the welfare cost of rent. Giving away too high rent will under a distortionary tax system be socially undesirable; hence a higher foreign ownership share will increase the government's incentive to extract rent. Rent extraction is in the model accomplished by inducing the firm not only to reduce output and reduce pollution abatement, relative to complete information, but also to get a subset of the least efficient firm types to relocate to other regions. (This feature of the model is a consequence of the assumption about the relationship between outside option and emission efficiency.) One might say that the home government takes advantage of other countries practicing environmental dumping.

When a larger fraction of the firm is under foreigners' control, then, according to the domestic government's policy rules, an upwards adjustment in net emissions and a downwards adjustment in output will be triggered, along with inducing a larger fraction of the firm types to relocate. The reason for this adjustment is that rent extraction becomes more important, when foreigners' ownership share gets higher. For a fixed pattern of location, expected local pollution will, according to our assumptions, increase, but this effect is counteracted by the government's desire to extract rent by getting a subset of the least efficient types to relocate. Hence, lower barriers to foreign ownership will not necessarily lead to higher local pollution.

Appendix A

- *Incentive compatible mechanisms*

According to the revelation principle, any regulatory scheme can be represented by a direct revelation mechanism, where the firm is asked to report its type. The regulator is, by assumption, able to design (and commit to) a mechanism so as to induce truthtelling. Within the present context, where both output (y) and level of pollution or net emissions (x), along with taxes (T), can be verified, a truth-telling mechanism can formally be represented by a triple, which specifies a transfer, a required output level and net emissions for any report $\hat{\theta} \in \Theta$ of the firm's type $\{T(\hat{\theta}), y(\hat{\theta}), x(\hat{\theta})\}$. Let the set of types that should be induced to continue operations at home, and therefore be motivated to participate in the domestic regulatory game be $\Xi \subseteq \Theta$, whereas the complementary set (which might be empty), i.e. those types that should be induced to relocate is Σ. For types in Ξ, which is to be determined, we restrict attention to piecewise continuously differentiable mechanisms.

Let $u(\hat{\theta},\theta) \equiv \pi(y(\hat{\theta})) - v(\theta y(\hat{\theta}) - x(\hat{\theta})) - T(\hat{\theta})$ be net utility or rent achieved by a θ-firm when announcing its type to be $\hat{\theta}$. Optimising at points of differentiability yields a first-order condition (IC_1) and a local second-order condition (IC_2) for incentive compatibility, both necessary for truthful revelation; i.e. $\hat{\theta} = \theta$, as given by

$$(IC_1) \quad \pi'(y(\theta)) \cdot \frac{dy(\theta)}{d\theta} - v'(\theta y(\theta) - x(\theta)) \cdot (\theta \frac{dy(\theta)}{d\theta} - \frac{dx(\theta)}{d\theta}) - \frac{dT(\theta)}{d\theta} = 0$$

$$(IC_2) \qquad y(\theta) \cdot v'' \cdot \frac{dx(\theta)}{d\theta} - \left[v' + \theta y(\theta) v''\right] \cdot \frac{dy(\theta)}{d\theta} \geq 0$$

These conditions are sufficient for truthtelling for any $\theta \in \Xi$; hence we can conclude that for any $(\theta,\hat{\theta}) \in \Xi$, we have $U(\theta) \equiv u(\theta,\theta) \geq u(\hat{\theta},\theta)$. For any allocation that obeys (IC_1) and (IC_2), rent accruing to a firm has to obey

(A-1) $\quad \text{For any } \theta \in \Xi \begin{cases} \dot{U}(\theta) = -y(\theta) \cdot v'(\theta y(\theta) - x(\theta)) \\ U(\theta) \geq R(\tilde{y}, \theta) \end{cases}$

(A-2) $\quad \text{For any } \theta \in \Sigma, U(\theta) = R(\tilde{y}, \theta)$

For types of the firm that should be induced to relocate, rent will be equal to the firm's outside option. On the other hand, for those types that should be motivated to continue operations at home, rent cannot fall below the value of the outside opportunity, and must be declining in θ so as to ensure truthtelling. (As noted in the text, the outside option, and hence the participation constraint, is type-dependent, and, by assumption, non-decreasing in θ.) Note also that a set of sufficient conditions for (IC_2) to hold is that the emission path is non-decreasing and the output path is non-increasing on Ξ.

Appendix B

- *The solution to [RP] in section 3*

We'll solve this problem in two stages: First, find the set of optimal control variables, and the associated state variable, that solves the problem [RP] for some fixed value of ξ in the interior of Θ. Then we detemine the optimal cut-off type. We will ignore the second-order condition (IC_2) when solving this problem. (This seems to be a drastic shortcut, but intuitively there is sufficient concavity in the problem so as to justify it.)

For some fixed $\xi \in (\underline{\theta}, \overline{\theta})$, let the solution to the sub-problem in (B-1) below be denoted { $x^0(\theta), y^0(\theta), U^0(\theta)$ }; where

$$max_{(x,y)} \int_{\underline{\theta}}^{\xi} \left[S(\theta, x(\theta), y(\theta)) - \gamma U(\theta) \right] f(\theta) d\theta$$

s.t.

(B-1) $\quad y \in [0, \tilde{y}]$ and $x \in [0, \theta y]$ for any $\theta \in \Xi$

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

$$U(\underline{\theta}) \text{ is free}, U(\xi) \geq R(\tilde{y}, \xi)$$

In this problem (x, y) is the pair of control variables, U is a continuous state variable whereas $\lambda(\theta)$ is the costate variable in the Hamiltonian of the problem, as given by:

$$(B\text{-}2) \qquad H(\theta,x,y,U,\lambda) = \left[S(\theta,x,y) - \gamma U\right] f(\theta) - \lambda y v'(\theta y - x)$$

The costate variable has to obey:

$$(B-3) \qquad \begin{cases} \dot{\lambda}(\theta) = \gamma f(\theta) \\ \lambda(\underline{\theta}) = 0 \\ \lambda(\xi) \geq 0 \, (= 0 \text{ } if \text{ } U^0(\xi) > R(\tilde{y},\xi)) \end{cases}$$

(We can immediately conclude that $\lambda(\theta) = \gamma F(\theta)$, with $U^0(\xi) = R(\tilde{y},\xi)$.) Suppose that for any $y \in (0,\tilde{y})$ and for any $\theta \in \Xi$, we have that

$$(B\text{-}4) \qquad -D'(\theta y) f(\theta) + \gamma y v''(0) < 0$$

This condition will, along with our previous assumptions, be sufficient for any pair (x, y) that jointly satisfies

$$(B\text{-}5) \qquad \begin{cases} \dfrac{\partial H}{\partial x} = \dfrac{\partial S}{\partial x} f(\theta) + \lambda y v''(\theta y - x) = 0 \\[2ex] \dfrac{\partial H}{\partial y} = \dfrac{\partial S}{\partial y} f(\theta) - \lambda(v' + \theta y v'') = 0 \end{cases}$$

in the interior of the control regions; $x \in (0, \theta y)$ and $y \in (0, \tilde{y})$.

(If we could have established that the Hamiltonian is jointly concave in (x, y, U) for any $\theta \in \Xi$, then the candidate obeying (B-5) will, according to the Mangasarian sufficiency theorem, be optimal; see Theorem 4 in chapter 2 in Seierstad and Sydsæter (1987). If strict concavity of H could be assured, then we would have a unique optimal solution.) For this property to hold, one is normally forced to impose some very restrictive assumptions. It can be verified that a sufficient condition for H to be strictly concave in (x, y, U) is

(B-6) $$2D''(x) \geq \gamma v''(\theta y - x)$$

which we'll expect not to hold for y close to the upper bound $\tilde{y}$ and x close to zero, for $\gamma > 0$. (For γ close to zero, (B-6) will trivially hold.)

Further examination of the properties of the Hamiltonian will convince us, for some given cut-off type ξ, that a unique optimal solution $\{ x^0(\theta), y^0(\theta), U^0(\theta) \}$ will exist, with x^0 and y^0 in the interior of each control region, so that *(A-1)* as well as *(B-5)* will be satisfied for $\{ x^0(\theta), y^0(\theta), U^0(\theta) \}$.

However, there is one qualifier. The candidate must obey (IC_2). Because it is a rather tedious task to check whether (IC_2) will be satisfied or the sufficient conditions for (IC_2) to hold, we assume rather drastically that the emission path, $x^0(\cdot)$, is increasing and the output path, $y^0(\cdot)$, is declining throughout Ξ. (This is not very drastic when γ is close to zero. However, if the marginal cost of public funds is high along with a high foreign ownership share, the claim that (IC_2) will hold might be too restrictive. If (IC_2) should not be satsified, we might end up with a solution involving some bunching, which is beyond the scope of the present paper.)

Given $\left\{ x^0(\theta), y^0(\theta); \forall \theta \in \Xi \right\}$ which obeys (B-5), as well as (IC_2) and (A-1), we can now define the maximal value of the integral in (B-1) as $w(\xi)$, as given by

(B-10) $$\begin{aligned} w(\xi) := \int_{\underline{\theta}}^{\xi} \left[S(\theta, x^0(\theta), y^0(\theta)) - \gamma \frac{F(\theta)}{f(\theta)} y^0(\theta) v'(\theta y^0(\theta) - x^0(\theta)) \right] f(\theta) d\theta \\ - \gamma F(\xi) R(\tilde{y}, \xi) \end{aligned}$$

where we have used the state equation and the binding end-point constraint, so as to get:

$$\int_{\underline{\theta}}^{\xi} U^0(\theta)f(\theta)d\theta = F(\xi)R(\tilde{y},\xi) + \int_{\underline{\theta}}^{\xi} y^0(\theta)v'(\theta y^0(\theta) - x^0(\theta))\frac{F(\theta)}{f(\theta)}f(\theta)d\theta$$

The optimal cut-off type, ξ^0, for some given foreign ownership share, is then found as the solution to the following stage-two problem:

Optimal cut-off: $$Max_{\xi\in\Theta}\left\{G(\xi):=w(\xi)+\alpha\int_{\xi}^{\overline{\theta}}R(\tilde{y},\theta)f(\theta)d\theta\right\}$$

According to condition (5) in the text, we have $\xi^0 > \underline{\theta}$. Hence we have:

$$(B-11)\quad G'(\xi^0) = w'(\xi^0) - \alpha R(\tilde{y},\xi^0)f(\xi^0) \geq 0 \ \ with\ \xi^0 = \overline{\theta}\ if\ G'(\overline{\theta}) \geq 0$$

On using (B-10), we find that the optimal cut-off type has to obey

$$\text{(B-11)'}\qquad W^0(\xi^0) - \gamma\frac{F(\xi^0)}{f(\xi^0)}\cdot\left[y^0(\xi^0)v'(\xi^0 y^0(\xi^0) - x^0(\xi^0)) - c'(\xi^0)\right] \geq 0$$

where $W^0(\xi^0) := S(\xi^0, x^0(\xi^0), y^0(\xi^0)) - (1+m)R(\tilde{y},\xi^0)$

We have assumed that the optimal cut-off type is in the interior of Θ, because the outside option for types in the upper part of the distribution, as well as the cost of leaving rent for types that do not relocate will become sufficiently high. Hence, from a welfare point of view, the society will be better off by letting types in the upper part of the distribution to leave.

Appendix C

- *The impact of higher foreign ownership share (section 4)*

The first-order condition for an interior solution of the cut-off type, (B-11), be written as $\frac{\partial G(\xi^0;\alpha)}{\partial \xi} = 0$, with $\frac{\partial^2 G}{\partial \xi^2} < 0$ in the neighbourhood of the optimal cut-off type. (If we in addition to our previous assumptions suppose that $R(\tilde{y},\xi)$ is weakly convex in ξ, then $G(\xi;\alpha)$ is strictly concave in ξ. Note that the convexity of R is not necessary for G being strictly concave.) Hence we can write the cut-off type as a differentiable function of the domestic ownership share α; i.e. $\xi^0 = \xi(\alpha)$. Because we have

$$\text{(C-1)} \qquad \frac{\partial^2 G}{\partial \xi^2} \cdot \frac{\partial \xi^0}{\partial \alpha} + \frac{\partial^2 G}{\partial \xi \partial \alpha} = 0$$

with $\dfrac{\partial^2 G(\xi^0;\alpha)}{\partial \xi \partial \alpha} = \dfrac{F(\xi^0)}{f(\xi^0)}\left[-\dot{U}(\xi^0) - c'(\xi^0)\right] > 0$, we have $\xi(\alpha)$ being strictly increasing in α.

- *Comparative Statics (section 4)*

Let us rewrite the first-order conditions in (B-5) so that $h_j := \dfrac{\frac{\partial H}{\partial j}}{f(\theta)}$, for j = x, y; and suppose that the Hamiltonian is concave in the neighbourhood of (x^0, y^0) for any $\theta \in \Xi$, with $y^0 \in (y^c, y^*)$. On differentiating (B-5), we then get

$$\text{(C-2)} \qquad \frac{\partial x^0}{\partial \alpha} = \frac{1}{|h|} \frac{F(\theta)}{f(\theta)} \left[y^0 v'' h_{yy} + (v' + \theta y^0 v'') h_{xy} \right]$$

$$\text{(C-3)} \qquad \frac{\partial y^0}{\partial \alpha} = \frac{1}{|h|} \frac{F(\theta)}{f(\theta)} \left[-(v' + \theta y^0 v'') h_{yy} - y^0 v'' h_{xy} \right]$$

where $|h| = h_{xx} h_{yy} - h_{xy}^2 > 0$, with

$$h_{xx} = -\left[(1+m)v'' + D'' + \gamma \frac{F(\theta)}{f(\theta)} y^0 v''' \right] < 0$$

$$h_{yy} = (1+m)(\pi'' - \theta^2 v'') - \gamma \frac{F(\theta)}{f(\theta)} (2\theta v'' + \theta^2 y^0 v''' < 0$$

$$h_{xy} = \theta(1+m)v'' + \gamma \frac{F(\theta)}{f(\theta)} (v'' + \theta y^0 v''') > 0$$

If we ignore some “pathological” cases, we can restrict attention to situations where the direct effects dominate leaving the expression in (C-2) to be non-positive, whereas the expression in (C-3) is non-negative.

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