E C O N O M I C S B U L L E T I N

Transboundary pollution, asymmetric information and social welfare

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Abstract

We consider two regulator−firm hierarchies with transboundary pollution, and firms may have private information about their marginal cost of production. The pollution of each firm is proportional to its production. The impact of asymmetric information on social welfare can be explained by a positive effect, which is the reduction of transborder pollution; one negative effect is the socially costly informational rents captured by firms. We show that, when the damage function is as such, the non−internalization of the transfrontier pollution is sufficiently important, then non−cooperating countries can get a higher expected or ex ante social welfare under incomplete information.

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1. Introduction

This paper evaluates the impact of asymmetric information on the expected social welfare of non-cooperating countries when there is transfrontier pollution and positive marginal social cost of public funds.

Acid rains and the ozone layer depletion due to nitrogen dioxide emissions, among other gazes, are examples of transborder pollution problems. Unless environmental agreements are made and enforced, these negative crossborder externalities are usually undergone and they negatively affect the victim countries.

By using a model of transboundary pollution, Chander and Tulkens (1992) show that the non-cooperating behavior of countries does not lead to the Pareto-optimality. Silva (1997) shows that there are circumstances under which decentralized governments efficiently control transboundary pollution in the presence of consumer/worker mobility and population crowding costs. Petrakis and Xepapadeas (1996) develop a mechanism that detects cheating and inducing the desired emissions even when the emission level of an individual country cannot be observed by the rest of the countries committed to cooperation to protect the international environment.

Closely linked to this work, is the one of Mansouri and Ben Youssef (2000). In this last paper, firms competing in a common market where they offer substitute or complementary goods, may have private information concerning their marginal cost of production, and are regulated by secret incentive contracts. We have shown that when there is a major transfer of pollution from one country to another and the firms' marginal costs are sufficiently high, competing countries are better off under incomplete information. Unfortunately, we have not answered the question of the average (i.e., ex ante) effect of asymmetric information on individual social welfare, and this is the main focus of the present paper.

This work has been inspired by the theoretical developments of Martimort (1996) who has analyzed competition between two hierarchical structures, each of which is composed of a manufacturer and a retailer. He has found that depending on the level of uncertainty on the marginal cost of the retailers and on the complementarity or substituability of their goods, manufacturers use a common or an exclusive retailer.

In this paper, we consider a symmetric game between two regulator-firm hierarchies. Each firm produces one good sold on the domestic market. The production process generates pollution which is proportional to production, and crosses the borders. Firms may have private information about their marginal cost of production and are regulated by incentive contracts supposing the existence of costly public funds.

Non-cooperative behavior does not internalize all the damages caused to the environment by the transboundary externality.

Incomplete information reduces production and, therefore, reduces pollution and the transboundary externality. The impact of asymmetric information on social welfare can be explained by two effects : a positive one, which is the reduction of transfrontier pollution; the negative one is the socially costly informational rents hold by firms. When firms are efficient, non-cooperating regulators are better off in complete information. Nevertheless, when firms are less efficient, they can be better off in incomplete information. This represents the first set of results which are in concordance with those of our earlier and above-mentioned paper.

The damage function for each country that we use is quadratic with respect to the total amount of pollution of the two countries. The non-internalization of transborder pollution by non-cooperating regulators is very important when the coefficient of the linear term of the damage function does not

equal zero. However, when the linear term equals zero (i.e., damages are proportional to the square of total pollution), the non-internalization of transboundary pollution is not very important.

We show that when the coefficient of the linear term of the damage function is non-nil, non-cooperating countries can get an individual expected social welfare, which is higher under incomplete information than under complete information. However, when the coefficient of the linear term is nil, non-cooperating countries have an individual expected social welfare higher under full information.

We conjecture that for both cases, i.e., a common market or separate markets and a damage function such as the non-internalization of transboundary pollution is relatively very important, non-cooperating countries can be in average (i.e., ex ante) better off in incomplete information. This result is worth considering since it goes against the standard intuition that the introduction of uncertainty leads to less social welfare because of, among other things, the socially costly informational rents captured by firms.

The paper is organized as follows. Section 2 presents the model. Section 3 compares the expected social welfare of complete and incomplete information. Section 4 concludes. Finally, all the proofs of propositions are gathered in an appendix.

2. The model

Our symmetric model consists of two countries and two firms. Firm i located in country i is a regional monopoly and produces good i in quantity q_i sold on the domestic market having the following inverse demand function : $p_i = a - bq_i$ with a,b>0.

The country regulates its domestic firm because this latter is a regional monopoly which pollutes the domestic environment, and to extract its profit because of the social cost of public funds.

Each regulator proposes a contract to his domestic firm, that may be accepted or rejected. Thus, regulator i proposes a contract (q_i, T_i) to his firm, specifying a certain level of production q_i that firm i must produce, and a monetary transfer T_i. If the monetary transfer is negative, this means that the firm has to pay a tax. The reservation utility level of firms is assumed to be equal to zero. When firm i accepts the contract, it produces the specified quantity, receives the monetary transfer and the price is determined by the market.

The fixed emission/output ratio is e>0 and the pollution emission level of firm i is $E_i = eq_i$.

Damages in one country are caused by the total pollution following a quadratic form : $D_i = \beta(E_i + E_j) + \gamma(E_i + E_j)^2$, $(\beta, \gamma) \in \Re_+^2 - \{(0,0)\}$.

Such a damage function expresses many international environmental problems such as the ozone layer depletion or global warming which are caused by the total emissions of gazes such as the carbon dioxide.

When γ=0, the damage function is linear with respect to the total pollution; the damages caused to country i by the transboundary pollution E_j cannot be internalized by regulator i because they are a function of q_j; therefore, the non-effective internalization of the transfrontier externality is very important because the imported pollution is totally uncontrolled.

However, when β=0, damages are proportional to the square total pollution and the non-cooperative behavior of regulators partially internalizes the transboundary pollution, implying that the non-effective internalization is not very important because the imported pollution is not totally uncontrolled.

When $\beta \neq 0$ and $\gamma \neq 0$, the higher β is the more important the non-effective internalization of transboundary pollution by non-cooperating regulators is.

The consumer surplus in country i derived from the consumption of q_i is $C_i = \int_0^{q_i} p_i(t)\,dt - p_i(q_i)q_i = \frac{b}{2}q_i^2$.

Because of distortionary taxation,[1] transfers to firms are socially costly. We denote the marginal social cost of public funds by $\lambda > 0$.

The consumer welfare of country i is equal to the consumer surplus minus damages and the monetary transfer which is pondered by $(1+\lambda)$ i.e. $C_i(q_i) - D_i(q_i, q_j) - (1+\lambda)T_i$.

The profit of firm i is $\Pi_i = p_i(q_i)q_i - \theta q_i$, where θ is the marginal cost of production verifying $a > \theta > 0$.

Then, the net profit of firm i is equal to the monetary transfer plus the profit : $U_i = T_i + \Pi_i(q_i, \theta)$.

Finally, the social welfare of country i is equal to the consumer welfare plus the net profit of the firm, which can be written as :

$W_i = S_i(q_i, q_j, \theta) - \lambda U_i$, where $S_i = C_i(q_i) - D_i(q_i, q_j) + (1+\lambda)\Pi_i(q_i, \theta)$.

In complete information, each regulator i maximizes his social welfare with respect to q_i and U_i under the rationality constraint of firm i. We allow ourselves to express the regulator's problem in function of U_i rather than T_i because these latter are one-to-one related.

Let's notice that instead of using a menu of direct contracts for their firms, completely informed regulators can use two instruments : a Pigouvian tax per unit of emission to induce the socially desired levels of production and pollution, and a lump sum tax on profit to extract all the profit of the firm.

In the incomplete information setting, θ is the private information for each firm and regulators have knowledge of the uniform distribution of θ on $\left[\underline{\theta}, \overline{\theta}\right]$ with the probability density f, and the uniform distribution F. By changing the monetary unit, we can always have $\overline{\theta} - \underline{\theta} = 1$.

Regulator i offers a contract $(q_i(\hat{\theta}_i), T_i(\hat{\theta}_i))$ to firm i where $\hat{\theta}_i$ is the value of the private information announced by firm i, $q_i(\hat{\theta}_i)$ is the level of production that the firm has to produce and $T_i(\hat{\theta}_i)$ is the monetary transfer to firm i. The nature of the contracts that we describe does not allow regulators to contract on any kind of ex post information, such as price information, to increase their expected social welfare.

Whether contracts are public or secret, this has no impact on the analysis since firms do not directly interact (separate markets).

The net profit of firm i is $T_i(\hat{\theta}_i) + \Pi_i(q_i(\hat{\theta}_i), \theta)$, where θ is the true value of the private information.

There is a temptation for each firm to announce a higher value than the true value in order to make the regulator believe that it has high costs and, accordingly, pays lower tax (or receives higher monetary transfer). Therefore, the contract proposed by regulator i must provide incentives to firm i to reveal the true value of θ :

$$\theta \in \arg_{\hat{\theta} i} \max \left\{ T_i(\hat{\theta}_i) + \Pi_i(q_i(\hat{\theta}_i), \theta) \right\}, \forall \theta \in \left[\underline{\theta}, \overline{\theta}\right]$$

Once the adverse selection parameter is known, the social welfare of country i is :

[1] See Ballard *et al*. (1985) and Laffont (1994) for further details.

$$W_i(q_i(\theta), q_j(\theta), \theta) = S_i(q_i(\theta), q_j(\theta), \theta) - \lambda U_i(\theta)$$

Regulator i maximizes the mathematical expectation of his social welfare function with respect to $q_i(.)$ and $U_i(.)$ under the revelation and rationality constraints of the domestic firm.

3. Complete versus incomplete information

In what follows, we suppose that condition (A1), defined in the appendix, is verified because it assures that the non-cooperative optimal production quantities are positive.

In the appendix, we show that the production quantities of incomplete information are lower than those of complete information, with equality only when $\theta = \underline{\theta}$. This is done to restrict the socially costly informational rent of the firm.[2]

Each firm has an informational rent decreasing with θ and is equal to zero only when $\theta = \bar{\theta}$. Indeed, when $\theta = \bar{\theta}$, each firm that tries to overestimate its private information cannot do it and, therefore, has no informational rent. When the marginal cost decreases, the set of possible announcements increases and so does the net profit of each firm.

Since pollution is proportional to production, uncertainty reduces both pollution and the transfrontier externality. Therefore, the lack of information of regulators eases the transborder externality problem.

Proposition 1. *i)Non-cooperating countries get a higher social welfare under complete information when the marginal cost is sufficiently low.*
ii)If βe or γe^2 are high enough, then non-cooperating countries get a higher social welfare under incomplete information when the marginal cost is high enough.

Indeed, the impact of uncertainty on social welfare can be explained by two effects: a positive one, which is the reduction of transborder externality, and a negative one, which is the socially costly informational rents captured by firms.

When the marginal cost is equal to its lower value, complete and incomplete information production quantities are identical implying no reduction of the transborder externality effect of uncertainty; nonetheless, firms have informational rents and that is why non-cooperating regulators are better off in complete information.

When the marginal cost is equal to its higher value, firms have no informational rents; asymmetric information productions are lower than the ones of complete information; however, when βe or γe^2 are sufficiently high, the reduction of transboundary pollution positive effect of uncertainty is relatively important and implies greater individual social welfare under incomplete information.

Since the socially costly informational rents (equal zero only in $\theta = \bar{\theta}$) and the incomplete information production quantities (equal those of complete information only in $\theta = \underline{\theta}$) decrease with the marginal cost, the individual social welfare may be too high or too low with respect to the non-cooperative optimum of full information. To get the average (i.e., ex ante) effect of uncertainty, we shall compare the expected social welfare in both informational regimes.

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[2] $\dot{U}_i(\theta) = -q_i(\theta) < 0$ (see the appendix) : when θ decreases from $\bar{\theta}$, $U_i(\theta)$ increases less rapidly if $q_i(\theta)$ is lowered. In $\underline{\theta}$, there is no longer a need to lower $q_i(\theta)$, that is why $q_i(\underline{\theta}) = q_i^*(\underline{\theta})$.

Proposition 2. *i)If $b=0$, non-cooperating countries get a greater expected social welfare under complete information.*
ii)If $b>0$ and (be or ge^2 are sufficiently high), non-cooperating countries get a greater expected social welfare under incomplete information.

Countries are better off ex ante, or in average, under asymmetric information only when the non-effective internalization of transborder pollution is relatively important. This is the case when the linear coefficient of the damage function is not nil. Otherwise, when damages are proportional to the square of total pollution, they have a greater expected social welfare under full information.

Even if our results have been shown for separate markets, they can be extended to the case of a common market. Indeed, when markets are opened to international trade, we show that non-cooperating countries can be ex ante better off under asymmetric information, in the case of a linear damage function with respect to the total pollution.[3]

We conjecture that we can get such a result for both cases, i.e., separate markets or a common market with damage functions exhibiting an important non-effective internalization of transboundary pollution when countries act non-cooperatively.[4]

4. Conclusion

We have studied the effect of incomplete information on the expected social welfare of non-cooperating countries when there is transboundary pollution and positive marginal social cost of public funds.

Non-cooperation does not effectively internalize all the transboundary pollution, while cooperation, obtained by maximizing the sum of social welfare of countries, gives the first best. Under asymmetric information, yardstick competition[5] enables the cooperating regulators to extract the common information of firms without any informational cost, and implement the cooperative equilibrium of full information. Indeed, when firms have perfectly correlated private information, then truth telling is a Nash equilibrium when regulators cooperate.

The impact of asymmetric information on individual social welfare can be explained by two effects : a positive one, which is the reduction of transfrontier pollution; the negative one is the socially costly informational rents hold by firms. When firms are efficient, non-cooperating regulators are better off in complete information. However, when firms are less efficient, they can be better off in incomplete information. More interestingly, non-cooperating regulators can get a higher expected social welfare under asymmetric information when the damage function is as such the non-internalization of transboundary pollution is important.

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[3] In this case, firms produce perfect substitute goods sold in both countries with the following inverse demand function $p(q_i + q_j) = a - \frac{b}{2}(q_i + q_j)$. For tractability reasons, we choose a damage function linear with respect to the total pollution i.e. we take $\gamma=0$. We suppose that contracts are secret with respect to the rival hierarchy because this assumption is necessary to determine the first and second order local conditions for the revelation problem of firms. The secrecy of contracts can be justified by the high cost of evaluating or observing rival hierarchy confidential information. We suppose that firms have perfectly correlated marginal costs. We demonstrate that competing countries can get a higher expected social welfare under incomplete information.

[4] Such damage functions can have the following expressions $a(1-t)E_i + atE_j$ or $a((1-t)E_i)^2 + a(tE_j)^2$, where $t \in [0,1]$ is the proportion of pollution transferred from one country to another, and $\alpha>0$ indicates the evaluation of the damages caused to the environment.

[5] See Kwerel (1977) and Shleifer (1985).

Even though our main results have been highlighted with a symmetric model, they can be sustained in an asymmetric context. Indeed, let's consider the extreme case where the firm of the downstream country does not pollute at all, while the firm of the upstream country produces while polluting. Under asymmetric information, the downstream country will receive less transboundary pollution, which can make it better off than under complete information. Other asymmetries concerning, for instance, the emission/output ratio, the sensitivity of consumers to the environment or the size of the domestic market can be considered. It is likely that the country which receives relatively more damages from transboundary externality would benefit from incomplete information, under certain conditions.

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Appendix

In the complete information case, each regulator i maximizes his social welfare with respect to q_i and U_i under the rationality constraint of firm i. The non-cooperative optimal production quantities of complete information are :

$$q_i^*(\theta) = q^*(\theta) = \frac{(1+\lambda)(a-\theta) - b\varepsilon}{(1+2\lambda)b + 4\theta\varepsilon^2} = \frac{(1+\lambda)(a-\underline{\theta}) - b\varepsilon - (1+\lambda)(\theta-\underline{\theta})}{(1+2\lambda)b + 4\theta\varepsilon^2}$$

Firms have a zero net profit.

Under asymmetric information, the contract proposed by regulator i must provide incentives to firm i to reveal the true value of θ : $\theta \in \arg\max_{\hat{\theta}_i} \left\{T_i(\hat{\theta}_i) + \Pi_i(q_i(\hat{\theta}_i),\theta)\right\}, \forall \theta \in \left[\underline{\theta},\bar{\theta}\right]$.

Denoting the derivatives with respect to θ by a dot and the partial derivatives by subscripts, the first order local condition is : $\dot{T}_i(\theta) + \dot{q}_i(\theta)\Pi_{iq_i}(q_i(\theta),\theta) = 0$.

Following Martimort, we respectively get the new first and second order local conditions for the revelation problem of firm i : $\dot{U}_i(\theta) = \Pi_{iq}(q_i(\theta),\theta)$ and $\dot{q}_i(\theta)\Pi_{iq_iq}(q_i(\theta),\theta) \geq 0$.

Regulator i maximizes the mathematical expectation of his social welfare with respect to $q_i(.)$ and $U_i(.)$ under the revelation and rationality constraints of the domestic firm.

To simplify the optimization problem of each regulator, we replace the rationality constraint ($U_i(\theta) \geq 0$) by $U_i(\bar{\theta}) = 0$. This last equality seems logical since when the marginal cost is equal to its higher value, each firm trying to overestimate its private information, cannot do it and, therefore, has no informational rent. Moreover, we momentarily put aside the second order local conditions. We come to the non-cooperative Bayesian differentiable equilibrium and we check ex post these ignored constraints as well as the positivity of the equilibrium production quantities and the global optimality of the revelation problem of firms.

Thus, the simplified optimization problem of regulator i is :

$$\underset{q_i(.),U_i(.)}{Max} \int_{\underline{\theta}}^{\bar{\theta}} f(\theta)\left(S_i(q_i(\theta), q_j(\theta),\theta) - \lambda U_i(\theta)\right)d\theta$$

$$\dot{U}_i(\theta) = \Pi_{iq}(q_i(\theta),\theta)$$

$$U_i(\bar{\theta}) = 0$$

Denoting by $r_i(\theta)$ the multiplier of the incentive constraint, the Hamiltonian of the above mentioned problem is : $H_i(q_i,U_i,\theta) = f(\theta)\left(S_i(q_i,q_j(\theta),\theta) - \lambda U_i\right) + r_i(\theta)\Pi_{iq}(q_i,\theta)$.

The necessary (and sufficient due to the concavity of the Hamiltonian) Kuhn and Tucker optimality conditions are : $H_{iq_i} = 0$ and $\dot{r}_i(q) = -H_{iU_i} = lf(q)$.

As there is no transversality condition in q, we have $r_i(q) = lF(q) = l(q - q)$.

The non-cooperative optimal production quantities of incomplete information are :

$$q_i(q) = q(q) = \frac{(1+l)(a-q) - be - l(q-q)}{(1+2l)b + 4ge^2} = \frac{(1+l)(a-q) - be - (1+2l)(q-q)}{(1+2l)b + 4ge^2}$$

The above quantities are lower than those of complete information with equality only in $q = q$, and they are strictly positive iff :

$$(1+2l)(q-q) < (1+l)(a-q) - be, \forall q \Leftrightarrow 1+2l < (1+l)(a-q) - be \quad \text{(A1)}$$

The informational rent is strictly decreasing because $\dot{U}_i(q) = \Pi_{iq}(q_i(q), q) = -q_i(q) < 0$.

Therefore, each firm has an informational rent which is equal to zero only when $q = \bar{q}$.

The second order local condition of the revelation problem of each firm is verified since $\dot{q}_i(q)\Pi_{iqiq}(q_i(q), q) = -\dot{q}_i(q) > 0$.

To verify the global optimality of the revelation problem of each firm, let's consider the difference :

$$\Delta_i = T_i(q) + \Pi_i(q_i(q), q) - \left(T_i(\hat{q}_i) + \Pi_i(q_i(\hat{q}_i), q)\right).$$

Using the same reasoning as Martimort, we obtain : $\Delta_i = \int_{\hat{q}_i}^{q} \dot{q}_i(u) \int_{u}^{q} -1 \, dt \, du$.

Since $\dot{q}_i(u)$ is negative, then Δ_i is positive, which means that each firm gets a higher net profit when it announces the true value of its marginal cost.

The informational rent of each firm is :

$$U(q) = \int_{q}^{q} \dot{U}(u) \, du = A\left[\left((1+l)(a-q) - be\right)(\bar{q} - q) + \frac{1}{2}(1+2l)(q-q)^2 - \frac{1}{2}(1+2l)\right]$$

where $A = \frac{1}{(1+2l)b + 4ge^2} > 0$.

The expected informational rent is : $EU = \int_{q}^{q+1} U(q) \, dq = A\left[\frac{1}{2}\left((1+l)(a-q) - be\right) - \frac{1}{3}(1+2l)\right]$ (1)

The difference between the social welfare of complete and the one of incomplete information is :

$$W^*(q) - W(q) = (q^*(q) - q(q))\left[(1+l)(a-q) - 2be - \left((1/2+l)b + 4ge^2\right)(q^*(q) + q(q))\right] + lU(q)$$

When the marginal cost is low enough, countries are better off under complete information because $q^*(q) = q(q))$ and $U(q) > 0$.

By using the expressions of the non-cooperative optimal production quantities, we get :

$$W^*(q) - W(q) = lA^2(q-q)\left[(1+2l)(lb/2 + 4ge^2)(q-q) - 4ge^2(1+l)(a-q) - (1+2l)b\,be\right] + lU(q) \quad \text{(2)}$$

The term between the above square brackets X(θ) is negative in $\bar{q}$ iff :

$$X(\bar{q}) < 0 \Leftrightarrow 1 < \frac{4ge^2(1+l)(a-q) + (1+2l)b\,be}{(1+2l)(lb/2 + 4ge^2)}$$

If γ=0, then $X(\bar{q}) < 0 \Leftrightarrow be > \frac{l}{2}$

If γ≠0, then $X(\bar{q}) < 0 \Leftrightarrow (1+l)(a-q) > 1 + 2l + \frac{(1+2l)(l - 2be)b}{8ge^2}$

Due to condition (A1), this last inequality is verified when γ≠0 and (βe≥λ/2 or ge^2 is high enough).

Therefore, if βe or γe^2 are high enough, then countries get a higher social welfare under incomplete information when the marginal cost is high enough because $U(\bar{q}) = 0$.

In what follows, we are going to compare the expected social welfare of complete information (EW^*) to the one of incomplete information (EW).

To facilitate our computations, we rewrite expression (2) as:

$$W^*(q) - W(q) = lA^2\left[(1+2l)(lb/2 + 4ge^2)(q-q)^2 - \left(4ge^2(1+l)(a-q) + (1+2l)b\,be\right)(q-q)\right] + lU(q) \quad \text{(3)}$$

By integrating the first terms of the above difference of social welfare in the two informational regimes between $\underline{q}$ and $\bar{q} = \underline{q} + 1$, and using expression (1) for the last term, we get :

$$EW^* - EW = \lambda A^2 \left[(1/2 + \lambda) b \left((1 + \lambda)(a - \underline{q}) - 2/3 - \lambda \right) - \beta e ((1 + 2\lambda) b + 2\gamma e^2) \right]$$

If β=0, then $EW^* - EW > 0$ because of condition (A1). Indeed, when the linear term of the damage function is nil, the non-effective internalization of transboundary pollution by non-cooperating regulators is not very important, that is why countries get a higher expected social welfare under complete information.

If β≠0, then $EW > EW^* \Leftrightarrow \beta e ((1 + 2\lambda) b + 2\gamma e^2) > (1/2 + \lambda) b \left((1 + \lambda)(a - \underline{q}) - 2/3 - \lambda \right)$; this inequality is verified when βe or γe^2 are high enough, and it is not in contrast with (A1).

Thus, if β≠0 and (βe or γe^2 are sufficiently high), countries get a greater expected social welfare under asymmetric information.

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