Environmental Dumping, Transboundary Pollution and Asymmetric Information. Some Insights for the Environmental Regulation of the European Electricity Market.

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1. Introduction

Producing electricity affects the quality of the environment, and has direct and indirect impacts on human health and welfare. Although several aspects of electricity generation impose external costs on society, by far the main source of environmental externalities in the production of electricity is air pollution. Among air pollutants, the electricity sector contributes in a substantial way to the production of SO_2, CO_2, NO_x and to a much lower degree to heavy matter particulates[2].

However the environmental impact of electricity production is not by itself a compelling reason to single out the electricity sector in studying pollution regulation. The electricity sector has a number of peculiar characteristics, both technical and theoretical that call for special attention.

From the theoretical point of view, three issues are of particular interest, especially in view of the undergoing market liberalisation process that is taking place in the European Union:

1. The market structure of this sector has traditionally been characterised by natural monopolies or at best *imperfect competition*. Production, distribution and transmission of electricity have always been regarded as natural monopolies on a good of primary importance for households and, therefore, have always been heavily regulated.
Casual observation of the already deregulated Electricity markets[3] suggests that liberalisation of the European market will probably reduce but not completely remove the producers' market power, and will result, at best, in imperfect competition. The need of price regulation will remain, at least to protect small consumers[4].

2. In electricity generation the problem of *transboundary pollution* is particularly acute.[5] Emissions discharged in the atmosphere can cover large distances and it is not unusual that most of their impact occurs at a substantial distance from the source, even across national

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[2] In 1994, 35% of carbon dioxide emissions, 33% of nitrogen oxides, 70% of sulphur dioxides discharged in the United States came from electricity production. In the European Union in 1990, the figures for the electricity share in the emission of the first three pollutants were, respectively 26%, 18% and 50% (Source: CORINAIR90).

[3] For discussions of the issues related to the liberalization of the electricity market, see, for instance, Surrey (1996) and Green and Newbery (1992) for the British case and Brennan et al. (1996) for the American one.

[4] Thus, in principle, environmental regulation should not be considered disjointedly from price regulation in the case of electricity, and at least the welfare of the consumers should be taken into account by the regulating agency.

[5] For instance, in the case of Belgium, roughly 90% of air pollution from power plants is carried away by winds to other countries (EMEP Statistics).

borders. This is of course more likely to take place the smaller are the countries involved, and the higher are the stacks. Thus, this is bound to be a serious problem in a region of highly industrialised and relatively small countries as the territory of the European Union. From the point of view of pollution control, this implies that the policies that a supra-national European regulator would implement will generally differ from those that would be implemented in a non co-operative way by each of the member countries. Each country will only abate up to the point where its own marginal benefits equal its own marginal costs, and it will not consider the damage to other countries. One could delegate transboundary pollution problems to a supranational authority but the latter will have to tackle the moral hazard problem of countries pretending that they are net importers of emissions, or that they have high control costs.

3. Environmental protection is likely to interfere with free trade agreements. This will be the case when national governments foresee the opportunity to distort their environmental policy in order to create more favourable conditions for their national producers. This practice is often referred to as "ecological dumping" (or "eco-dumping" for short). This issue has raised considerable interest and has been widely explored in the literature[6]. A general consensus has been reached on the point that, while in a perfectly competitive setting there is no scope for eco-dumping practices, *they may well arise in an imperfectly competitive market setting like the one that is likely to characterise the European Electricity market.*

The concern that strategic behaviour on the part of national governments, induced by transboundary pollution and eco-dumping, may undermine both the benefits from trade liberalisation and environmental protection is a good reason why the members of a free trade agreement like the European Union may decide to delegate their environmental policies to a supra-national body like the European Commission. On the other hand, as Ulph (1997) suggests, it is quite natural that national governments will be able to attain a better understanding of the ecological effects and of the social and economic implication of their domestic environmental problems than a supra-national authority. National governments will be tempted to put this knowledge at the exclusive advantage of their own country. Thus *asymmetric information* problems may complicate further the regulatory issue.

The need of an international co-ordination of environmental policies is reflected in the active stand the European Commission has increasingly taken in steering, moulding and directing the Environmental Policies of the Member States. The European Environmental Policy has gone trough substantial changes since the early 70's, but it is safe to say that it presently shows particular concern for transboundary issues, for the need of gathering correct

[6] A survey can be found in Ulph (1994).

environmental information, and for the need to conciliate environmental protection with free exchange of goods[7].

A model in which the regulatory relationships arising in an international context are almost completely analysed, is A. Ulph (1997), which focuses on the problem of environmental regulation for the members of an international trade agreement. Ulph's principal goal is to study the effectiveness of harmonisation policies against eco-dumping.

Ulph's model is an extension to asymmetric information issues and environmental regulation of the Brander and Spencer (1985) framework. Brander and Spencer analysed the rent-shifting behaviour of two governments which try to support their national producer in an international Cournot duopoly, by means of export subsidies. These subsidies act as devices that commit national producers to a certain level of output and hence to an higher market share than the one they would have achieved in a simple Cournot equilibrium. An analogous role can be played in general by any external support that can help the domestic firm to commit to a certain level of output in case of Cournot competition, or to a certain price in case of Bertrand competition. These indirect commitment devices may be used when explicit trade policies are forbidden by trade agreements, by countries whose firms compete in oligopolistic market within the free trade area. Such policies shift the producers' reaction function in a favourable direction, and in a way that cannot be undone by the firms, that is, in a way that irrevocably reduces the set of strategies available to a player in the following stage of the game. National environmental policies, having a direct influence on the firms production costs, may be used by member states to this purpose.

The first applications of this idea to international environmental policy are due to Barrett (1994) for environmental standards and Conrad (1993, 1995) for taxes. These studies confirm the findings of Brander and Spencer. In particular they found that, compared to the naïve first best policies based on the rule that equates marginal social benefit to marginal social cost, environmental policies chosen by governments in the Nash equilibrium are tougher under Bertrand competition and lower under Cournot competition[8].

Various extensions to these basic applications can be found in the literature. The idea developed in Ulph (1997) is that the commitment device role that environmental policy may have under perfect information, can be enhanced under asymmetric information, by the

[7] For an analysis of the evolution of the EU environmental Policy, see Knill (1997).
[8] However, as Ulph points out, this divergence between Bertrand and Cournot competition may vanish when the comparison is drawn against a full cooperative equilibrium. In this case, depending upon the shape of the reaction functions, also Bertrand competition may result in a less strict policy in the non-cooperative equilibrium than in the cooperative one.

impossibility on the part of the European Commission to ascertain whether in each of the two regulated countries the environmental damage costs are high or low. Each government's objective is to maximise its national producer's profit net of the environmental damages that its emissions cause. National producers engage in Cournot competition in the international markets and in addition to their production costs they must also meet the abatement requirement set by the European Commission. National governments, which are assumed to have perfect knowledge of their own country's damage costs, are asked to report them to the Commission. Thus they have an incentive to misreport them in order to be assigned a less strict environmental policy, thus favouring their domestic producers in the international market. Hence, a principal-agent relationship takes place between the Commission and the governments. Ulph does not consider in his model asymmetric information between national governments and producing firms.

2. The Model

Ulph's main focus is on harmonisation of environmental policies at the European level, or in alternative on the use of common minimum requirements for environmental protection for all the European Countries. He seeks conditions under which these options can be welfare-improving for the members of a free trade area like the European Union. His model shows that there is very limited scope for introducing harmonisation and minimum standard policies at the European level when the Commission has full information about damage costs. However, he founds a rationale for harmonisation in the presence of asymmetric information. In fact, he shows that in this case less differentiated policies may be in order.

In the body of the paper, we will extend Ulph's model in order to analyse the interaction between environmental dumping and the issues posed by transboundary pollution. In particular, we are interested in the changes in the behaviour of the various actors due to the presence of transboundary pollution, and in how this extension of Ulph's model affects his conclusion about the opportunity of harmonised policies.

Transboundary pollution is an additional source of concern because of moral hazard issues. National governments will typically have no direct incentive to deal with the externalities that their national production causes abroad. Thus, in general, the environmental policies enforced independently by those governments will be too lax compared to those that would have been chosen in a first-best co-operative equilibrium.

Ulph chooses to disregard transboundary pollution issues in order to highlight the effect of international competition on environmental policies. His point is that we do not need transboundary pollution for the non co-operative equilibrium to result in levels of pollution higher than those that would prevail in the first best optimum. However, introducing these considerations in his framework will not prevent us to be able to distinguish between the effect of strategic behaviour in the international markets and the moral hazard effect of transboundary pollution. Typically, they will reinforce each other, leading to even less strict policies in the non co-operative equilibrium. Moreover, consideration of the latter issue has a direct bearing on Ulph's conclusion about the desirability of harmonisation policies.

The model can also be extended in a simple way to include consumers' surplus in the governments' welfare functions. Since it entails only minor differences with respect to Ulph's conclusions, consumers' surplus will not be considered in detail here. We will limit ourselves to discuss the main implications of this extension in the subsection 2.2 and to mention the main results in footnotes where relevant.

Finally, although in Ulph's model the policy instruments are either standards or taxes, we have chosen to leave the case of environmental taxes for further research, both for technical reasons and space constraints. Thus we will focus on environmental standards only.

2.1. Structure and Assumptions

We will now describe in detail the hypotheses and the logical structure of Ulph's model.
Ulph considers two alternative information structures (Symmetric or Asymmetric), and two alternative coalitional setting (non Co-operative and Co-operative) which give rise to four different regulatory situations, as in the table below:

Information → Coalition ↓	Symmetric	Asymmetric
No Co-operation	**I**	**III**
Co-operation	**II**	**IV**

Table 1. The Structure of The Model.

Under symmetric information, the model consists of a two stages game.

In the *first stage* of the game, each country's government decides upon the level of its environmental policy instruments. To fix ideas, one country will be the Home Country and the other the Foreign one. Each country will choose emissions standard levels in order to maximise the profits of its domestic firm minus environmental damages. The latter are the only element of asymmetry between countries in the model. If *e* are emissions in the Home Country and *f* are emissions in the Foreign Country, each unit of emission causes *dD(e)* and d*D(f)* damages respectively, where *D* >0 and *D* >0.

In order to introduce transboundary pollution in this framework, we assume that a fraction $0 < j \leq 1$ of each country's emissions will cause environmental damages to that country, and that a fraction $0 \leq k \leq 1$ will affect the other country welfare; the remainder $(1 - (j + k))$ will be dispersed in the biosphere and will have no effect on the two countries[9]. The case in which $j=0$ is obviously deprived of any interest. Moreover, it is logical to assume that $j + k \leq 1$, that is, each particle of pollutant will cause damages only once. We will also make quite a standard technical assumption, in order to simplify the analysis: each country's damage function is additively separable in the two firms' emissions: that is, environmental damages in the Home Country will be *d[D(je)+ D(kf)]* and those in the Foreign Country will be d*[D(jf)+D(ke)]*. This assumption is not completely harmless: it amounts to assume away all interaction effects between emissions from different sources. However, this will be of very limited consequence for our analysis, and it will make our algebra much more clear.

In the *second stage* two firms with identical production costs, located in two separate countries, engage in Cournot competition in the market of an homogeneous good. Ulph assumes that the whole production is sold to a third group of countries. Thus, domestic consumers are of no relevance in this framework. This yield to the Home Country's firm a revenue $R(x,y)$ where x is the output of the firm located in the Home Country and y is the output of the firm located in the Foreign one, and to the Foreign Country's firm a revenue $R(y,x)$, and where we assume $R_{11} < 0$, $R_{12} < 0$. The production costs for the Home Country's firm are $C(x)$ with *C (x) > 0* and *C (x) > 0*.

Each unit produced generates one unit of emissions, that can be abated at the cost $A(a)$, where a is the abatement level, so that $e = x-a$ are the net emissions in the Home Country. We assume that the cost of abatement is strictly increasing and convex. Each firm then maximises its profits taking as given the other firm's output and the level of the instruments chosen by the governments in the first stage of the game.

Under asymmetric information, in the case in which the two countries "co-operatively agree to delegate their environmental policy to the European Commission, the model consists of a three stages game. In the first stage, the two governments report their environmental damage parameters to the Commission. In the second stage, the latter assigns to each country an emission standard based contingent on the reports. In the third stage, firms engage again in Cournot competition.

All the games considered are solved by backward induction. Since the additional hypotheses we will introduce have no direct effect on the last stage of the game, we will replicate for convenience Ulph solution's for that stage in the environmental standards case in Subsection 2.3. Ulph's characterisation of the first stage of the game and of the overall solution will be retrieved as a special case of the more general ones we will present from Subsection 2.4 on. Subsection 2.4 itself will deal with the equilibria that arise under the assumption of full information about the environmental damage parameters. Subsection 2.4.1 will consider the non co-operative equilibrium. Subsection 2.4.2 will consider the co-operative equilibrium. Subsection 2.5 will deal with harmonisation and maximum environmental standard policies. In Subsection 2.6 we will focus on the equilibria that arise when we drop the assumption of complete information, but for the sake of comparison will start with a reconsideration of the full information equilibria under the hypotheses about the damage costs adopted in that section. Subsection 2.6.2 will then cover the non co-operative equilibria, and subsection 2.6.3 will cover the co-operative equilibria. In subsection 2.7 some simulation results will be presented and discussed.

In Ulph's paper, governments are concerned only about firms' profits and the direct effects of emissions in terms of environmental damages. However, one of the major point (perhaps *the* whole point) of enforcing trade liberalisation agreements, is that increased competition should enhance consumer's welfare. Disregarding it seems a bit questionable for a paper cast in a European Union framework[10]. In the rest of the paper we will nevertheless disregard the welfare of the consumer, but, before embarking in the analysis of the effects transboundary pollution, we would like to discuss briefly the reasons of this choice.

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[9] Note that, in order to limit the asymmetry between counties to the damage parameter, we assume that each of the two parameters *j* and *k* is the same for both countries.

[10] Also, electricity is indeed traded and sold within the European Union.

2.2. A digression on Consumers Surplus.

Suppose that national output of the two firms is sold to consumers in the Home Country, consumers in the Foreign Country and consumers in the third group of countries. National governments will be interested in the maximisation of the consumer surplus of their *own national* consumers. Now, there is perhaps an easy way to pick up national consumers. It is quite reasonable to assume that, due to transaction or transport costs, national consumers will prefer to buy from national producers. Suppose that trade agreements requires that equilibrium price and quantity must be univocally set in the international market, and that α is the share of production bought by national consumers, so that the firm located in the Home Country sells $\alpha X(e,f)$ in equilibrium to domestic consumers. In this case, the surplus of the Home[11] Country national consumers can be easily computed as:

$CS^H = \int_0^{\alpha X} Q^{-1}\big(X(e,f)Y(e,f)\big)dx - Q^{-1}\big(X(e,f)Y(e,f)\big)\alpha X$, where $Q^{-1}(X,Y)$ is the world inverse demand function, and where $\frac{\partial CS^H}{\partial X} > 0$, $\frac{\partial CS^H}{\partial Y} \leq 0$.

The assumption about the trade agreement is crucial here. It implies that no price discrimination is allowed. Indeed, if the national producer can rely on the fact that national consumers will not buy from his rival, the natural incentive for him will be to set a separate market within the national borders and act as monopolist on it. A less naïve approach would then try to derive conditions under which price discrimination will occur, but this will again amount to a much more complex market structure in the second stage. As a first approximation, however we can do away with these concerns simply by assuming that α will be strictly less than one. In fact, if all the firm's production is sold to her national consumers, which only buy from the national producer, this firm is *de facto* a monopolist and it will be very hard to enforce regulations that prevent her from behaving as such.

Let then the consumers' surplus for the Home Country be expressed as above. Taking as given the emission standards of the Foreign Country, the Home government would then choose the level of environmental standard *e,* that maximises the sum of consumers' surplus and profits net of the environmental damages at Home: $V^H = CS^H + \Pi^H - ED^H$

It is then quite easy to see that in such a formulation, the inclusion of consumer surplus will just replicate the incentives exerted on the national governments by firm profits: again, national governments will be happy to see national output expanded and foreign output

[11] The case of the Foreign Country is exactly symmetrical.

reduced, *ceteribus paribus*. Hence consumer's surplus consideration will lead national government to implement even less strict environmental policies[12].

2.3 Second Stage Game

We will consider now the Cournot game between producers. The Home Country's firm will chose x and the Foreign Country's firm will choose y to maximise, respectively,

$$\pi(x,y,\bar{e}) = R(x,y) - C(x) - A(x-\bar{e}) \qquad (1)$$

$$\pi(y,x,\bar{f}) = R(y,x) - C(y) - A(y-\bar{f}) \qquad (2)$$

taking as given the other's firm output and the emission standards $\bar{e}$ and $\bar{f}$ set in the first stage. Those standards must be interpreted as the (maximum) amount of emission tolerated, and firms are supposed to abate the amount they generate in excess. The resulting Nash Equilibrium outputs stem from solving simultaneously the first order conditions, which implicitly give the firms' reaction functions. We will refer to these equilibrium outputs as $X(\bar{e}, \bar{f})$ and $Y(\bar{f}, \bar{e})$.

It can be shown that $X_{\bar{e}} > 0,\ X_{\bar{f}} \leq 0,\ Y_{\bar{e}} \leq 0,\ Y_{\bar{f}} > 0,\ X_{\bar{e}} + Y_{\bar{e}} > 0,\ X_{\bar{f}} + Y_{\bar{f}} > 0,$ that is, if the Home Country government relaxes its environmental policy by tolerating higher emissions, this will result in higher production at home and lower production in the Foreign Country, and vice versa, and in an overall increase of industry output[13]. In equilibrium, the profit function of the Home firm entering the Home Country's objective function will be:

[12] The assumption of Cournot competition can be, in this regard, crucial. As Feenstra (1998) notes, it is possible that, "with Bertrand competition, consumers' interests do not coincide with firm interests. The government should balance increased home-firm profits with decreased consumer surpluses and increased environmental damages".

[13] Of course, corner solutions implying zero production are theoretically possible, if the damage parameter of a country is high enough. If for instance this holds for the Home Country, it would imply that $X_{\bar{f}} = 0$ because, independently from the market share (and hence the emissions) of the Foreign Country, the Home Country would be unable to reduce its output any further. However such situation is not so interesting from our point of view, because in absence of imperfect competition, there is no strategic incentive for the governments to support their producers by means of eco-dumping practices. We will thus focus on internal solutions only.

$\Pi^H(\bar{e},\bar{f}) = \Pi^H\left[X(\bar{e},\bar{f}),Y(\bar{e},\bar{f}),\bar{e}\right]$, where $\Pi^H_{\bar{e}} = R^H_y Y_{\bar{e}} + A' > 0$ for the envelope theorem, $\Pi^H_{\bar{f}} = R^H_y Y_{\bar{f}} < 0$, and analogous expressions hold for the Foreign Country. It can also be established that in general, $\Pi_{11} < \Pi_{12} < 0; \Pi_{22} < 0.$

2.4 The first stage game.

Given our assumptions, the objective functions of the Home and Foreign governments are, respectively:

$$V(e,f,d,j,k) = \Pi(\bar{e},\bar{f}) - d\left[D(j\bar{e}) + D(k\bar{f})\right] \quad (3a)$$

$$V(f,e,\mathrm{d},j,k) = \Pi(\bar{f},\bar{e}) - \mathrm{d}\left[D(j\bar{f}) + D(k\bar{e})\right]. \quad (3b)$$

It can be easily seen, by deriving twice the expressions above, that the following properties of the government's objective function hold:

$$V_{11} = \Pi_{11} - dj^2 D''(j\bar{e}) < V_{12} = \Pi_{12} < 0; \quad V_{13} = -jD'(j\bar{e}) < 0;$$
$$V_{14} = -dj\left[D'(j\bar{e}) + \bar{e}D''(j\bar{e})\right] < 0; V_{15} = 0.$$

$$V_{21} = V_{12} = \Pi_{12} < 0; \; V_{22} = \Pi_{22} - dk^2 D''(k\bar{f}) < 0; \quad V_{23} = -kD'(k\bar{f}) < 0;$$

$$V_{24} = 0; V_{25} = -dk\left[D'(k\bar{f}) + \bar{f}D''(k\bar{f})\right] < 0.$$

and we shall assume $V_{11} + V_{22} < V_{12} + V_{21} < 0$.

Some of the results above hinge on the additivity of the damage function. However, considering a more general convex damage function will have no major consequence on our analysis. In particular it will result in even more negative values of $V_{12} = V_{21}$ and in negative values for V_{15} and V_{24}. However, it will make our assumption about the sum of the second derivatives above a bit stronger.

We will now consider two different equilibria in environmental standards, the non co-operative equilibrium and the co-operative equilibrium.

2.4.1 Non Co-operative Equilibrium

Let the Home and Foreign Country set independently the level of their emissions standards to maximise their national welfare functions, taking as given the standards set by the other country. The first order conditions will then be

$$V_1\left(e,f,d\right) = \Pi_1 - djD'\left(j\bar{e}\right) = R_y^H Y_e + A' - djD'\left(j\bar{e}\right) = 0 \qquad \text{(4a)}$$

$$V_1\left(f,e,\mathrm{d}\right) = \Pi_1 - \mathrm{d}jD'\left(j\bar{f}\right) = R_x^F X_f + A' - \mathrm{d}jD'\left(j\bar{f}\right) = 0\,. \qquad \text{(4b)}$$

There are two major implications in these conditions.

First, since the terms R_yY_e and R_xY_f are positive, both governments will set emission standards such that the marginal abatement costs will be lower than the marginal damages. Emissions will thus be higher than those implied by the first best rule of equating marginal costs and marginal benefits. As Ulph notes, this can be explained by interpreting the terms R_yY_e and R_yY_e as "*strategic trade incentives* for each government to use its environmental policy to encourage the domestic firm to produce more output, since the government calculates that the rival firm will respond by reducing its output, thereby rising the profits of the domestic producer".

Second, notice that *k* has no influence on the equilibrium standards. In fact, each country can influence only its own emissions and thus has no direct way to protect herself against the environmental damages caused by its counterpart's emissions, but also does not consider in its own policy the damages it causes to the other country. Indirectly, however, this lack of protection against transboundary pollution reinforces the strategic trade incentives, since reducing the rival's market share implies reducing its emissions too.

From the first order conditions, one gets the reaction functions: $\bar{e} = \mathrm{P}^H(f, d, j)$ and $\bar{f} = P^F(e, \mathrm{d}, j)$, where, by the implicit function theorem

$$-1 < \mathrm{P}_1 = -\frac{V_{12}}{V_{11}} < 0;\ \mathrm{P}_2 = -\frac{V_{13}}{V_{11}} < 0 \text{ and } \mathrm{P}_3 = -\frac{V_{14}}{V_{11}} < 0. \qquad (5)$$

The reaction functions are thus downward sloping and stable[14]. An increase in the environmental damage parameter of a country shifts the reaction function of that country inwards. The same effect has an increase in the share of emission causing local damage (*j*).

[14] The economic reason for the slope of the reaction function has been described by Ulph as follows: "when the Foreign Country toughens its emission limit, that will force the foreign firm to cut its output and allow the domestic firm to expand its output. If the domestic government kept its emission limits unaltered the domestic firm would have to match the increase in output with exactly the same increase in abatement raising marginal abatement costs, but leaving marginal damage costs unaffected. The

The equilibrium emission limits $\hat{e}$ and $\hat{f}$ are found by solving simultaneously the reaction functions above, and of course each of them fulfils its respective first order condition (4a) or (4b).

Figures 1 and 2 below illustrate some proprieties of the non co-operative equilibrium. Notice that an increase in *d* results in a toughening of the Home Country's emission limits, from $\hat{e}$ to $\hat{\hat{e}}$ and in a relaxation of the Foreign Country' limits, which increase from $\hat{f}$ to $\hat{\hat{f}}$. Thus we have $\frac{\partial \hat{e}}{\partial d} < 0$ and $\frac{\partial \hat{e}}{\partial \mathrm{d}} = \frac{\partial \hat{e}}{\partial \bar{f}} \frac{\partial \bar{f}}{\partial \mathrm{d}} > 0$; analogously for $\hat{f}$ we have $\frac{\partial \hat{f}}{\partial \mathrm{d}} < 0$ and $\frac{\partial \hat{f}}{\partial d} > 0$.

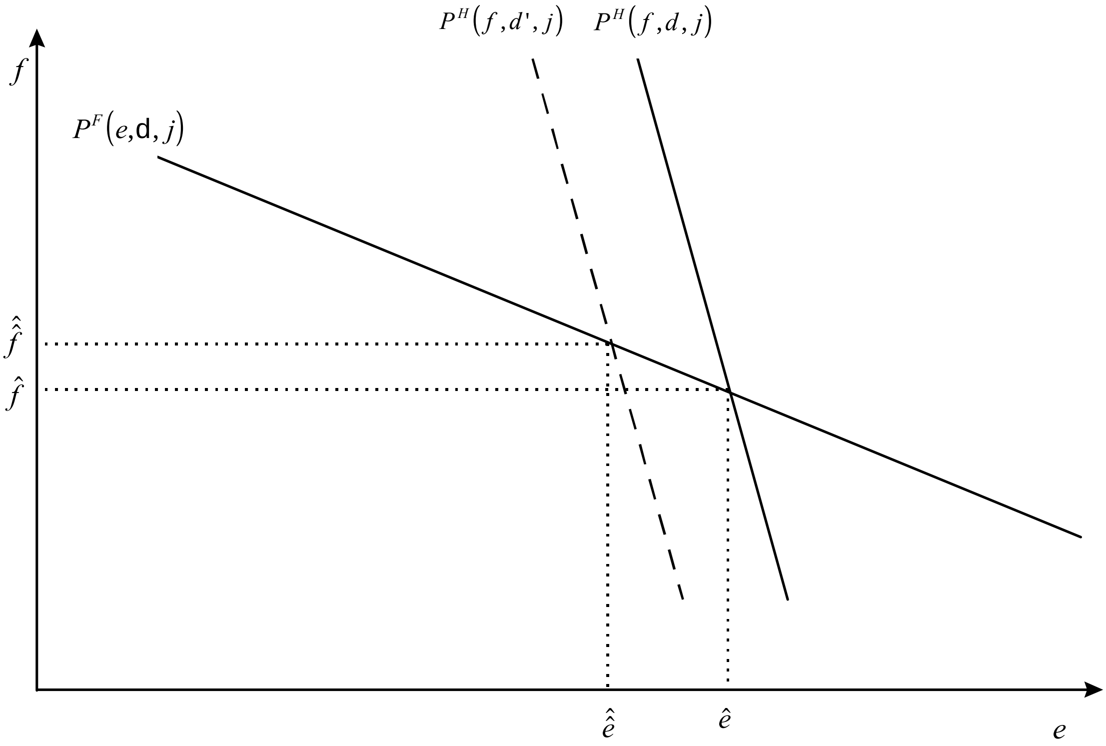

Figure 1. Non Co-operative equilibrium proprieties. An increase from *d* to *d* .

Notice also, that, since $P_3 < 0$, a decrease in *j* will result in an outward shift of both reaction functions. On the other hand, we know that no effect will be produced by an increase of *k*. Thus, the net effect of introducing transboundary pollution in the non co-operative equilibrium will be a relaxation of the environmental policies of both countries (that is, $\frac{\partial \hat{e}}{\partial j} < 0$, $\frac{\partial \hat{f}}{\partial j} < 0$), as depicted in Figure 2.

optimal policy would be to have some of the extra output show up as extra pollution. Thus when governments use emission limits, their policies are *strategic substitutes*".

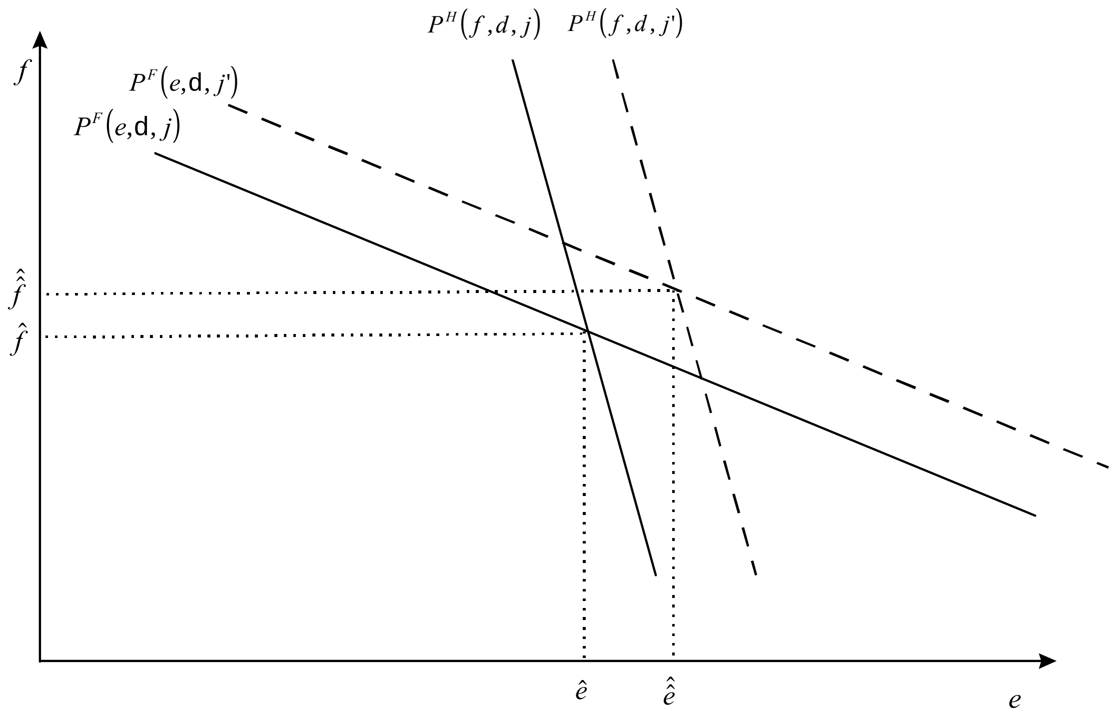

Figure 2. Non Co-operative equilibrium proprieties. A decrease from *j* to *j* .

To sum up, two differences with the no transboundary pollution case considered by Ulph, can be highlighted. First, domestic emissions become less important for each player which can now count on a sort of costless and natural "abatement technology" to have these emissions partially curbed. On the other hand, each country will suffer environmental damages caused by its counterpart's emissions, and has no way to protect herself against them, but also will not consider in its own policy the damages it causes to the other country.

Finally we can denote the equilibrium welfare level of the Home Country as

$$\hat{V}^H(d,\mathrm{d},j,k) = V\left[\hat{e}(d,\mathrm{d},j),\hat{f}(\mathrm{d},d,j),d,j,k\right] \qquad (6)$$

where, for the envelope theorem,

$$\hat{V}_d^H = V_f\hat{f}_d + V_d < 0,\ \hat{V}_{\mathrm{d}}^H = V_f\hat{f}_{\mathrm{d}} > 0\ \ \hat{V}_k^H = V_k = -dD' < 0 \qquad (7)$$

and the sign of $\hat{V}_j^H = V_f\hat{f}_j + V_j$ depends on *j* and *d.* In fact the first term of the RHS in the latter expression is the indirect effect of an increase of *j* on the welfare of the Home Country and is positive since an increase in *j* (i.e. the effect of domestic emissions within the national border of each country) reduces reduce the output of the foreign firm, thus leaving an higher market share, and hence higher profits to the home firm[15]. The second term, on the other hand, is the direct (negative) effect on welfare of an increase of the weight of domestic pollution in the damage function.

2.4.2 Co-operative Equilibrium

In the co-operative equilibrium the two countries' governments decide together on the levels of their environmental policy instruments in order to maximise the sum of their welfare functions $W=V(e,f,d)+V(e,f,\mathrm{d})$. We characterise this equilibrium as a full information benchmark for the principal-agents model analysed in section 2.6, and we will not question, at this stage, whether or not it Pareto-dominates the non co-operative equilibrium.

The two governments will decide together upon the levels of e and f that maximise $W=V(e,f,d)+V(e,f,\mathrm{d})$, where now $V(e,f,d)$ and $V(e,f,\mathrm{d})$ are as in (3a) and (3b).

The first order conditions for this problem are:

$$V_1(e,f,d)+V_2(f,e,\mathrm{d}) = R_2(X_e+Y_e)+A'-[djD'(je)+\mathrm{d}kD'(ke)]=0 \qquad \text{(8a)}$$

$$V_2(e,f,d)+V_1(f,e,\mathrm{d}) = R_2(X_f+Y_f)+A'-[djD'(jf)+\mathrm{d}kD'(kf)]=0\,,$$

where we have exploited the fact that $R_2 = R_y^H = R_x^F$.

Solving simultaneously the first order conditions for e and f one gets the equilibrium values for $e^*(d,\mathrm{d}, j, k)$ and $f^*(d,\mathrm{d}, j, k)$.

Comparing the equilibrium standards with those chosen in the non co-operative equilibrium it can be shown that $e^* < \hat{e}$ and $f^* < \hat{f}$. In fact, consider for instance condition (8a). It implies that e^* fulfils this condition:

$$A' = djD'(je^*)+\mathrm{d}kD'(ke^*)-R_2(X_e+Y_e)\,, \qquad \text{(9a)}$$

and that f^* fulfils this condition:

$$A' = \mathrm{d}jD'(jf^*)+dkD'(kf^*)-R_2(X_f+Y_f)\,. \qquad \text{(9b)}$$

In the non co-operative equilibrium it was just required, for $\hat{e}$, that $A' = djD'(j\hat{e})-R_y^h Y_e$, and for $\hat{f}$, that $A' = djD'(j\hat{f})-R_x^f X_f$.

---

[15] Notice that, due to the envelope theorem, the analogous effect on the Home Country welfare of national emissions, $V_e \hat{e}_j$, is zero, since the equilibrium emission standards in the Home Country are chosen to maximize Home Country's welfare, and thus satisfy the first order condition $V_e=0$.

Since both $\mathrm{d}kD'\left(ke^*\right)$ and $-R_2\left(X_e+Y_e\right)$ in the RHS of condition (9a) are positive, this rule requires that the emission limits for the Home Country must be set above the marginal environmental damages caused by domestic emissions to the national environment. Thus, emission limits will be stricter than those prescribed by the first best rule (in the absence of transboundary pollution) of equating marginal abatement costs to marginal environmental damages. This happens for two reasons. First, as noted by Ulph, “the governments of the two countries wish to encourage their firms to move closer to the industry maximising level of profits, and this requires reducing output from the Cournot level”. Second, also the transboundary effect of domestic emission must now be taken into account, and this requires a further reduction in output and emission which was not required in Ulph’s framework. When the effects of transboundary pollution are strong, each country is basically imposing a (possibly heavy) negative externality on its counterpart. Joint maximisation of the two countries’ welfare will lead them to internalise these external costs.

In general the signs of $\frac{\P e^*}{\P d}, \frac{\P e^*}{\P \mathrm{d}}, \frac{\P f^*}{\P d}$ and $\frac{\P f^*}{\P \mathrm{d}}$ depend on *j* and *k*. The derivation of these signs is rather cumbersome. Fortunately, some insights can still be provided in an intuitive way by conditions (9).

a) When *j* tends to 1 and *k* to 0, domestic emissions will have (almost) no direct effect on the Foreign Country’s damages, and foreign emissions will have (almost) no influence on domestic damages. Also, an increase in *d* will affect directly (almost) exclusively the Home Country, where marginal damages will be higher, thus requiring more abatement of domestic emissions. This will leave the environmental situation of the Foreign Country (almost) unaffected, but will result in a reduction of industry output. It will then be efficient to increase production and pollution in the Foreign Country. By continuity, the same effects should take place as long as *j* is sufficiently large compared to *k*. Thus, when *j is sufficiently large compared to k*[16], we have $\frac{\P e^*}{\P d} < 0$ and $\frac{\P f^*}{\P d} > 0$; by symmetry it must then be $\frac{\P e^*}{\P \mathrm{d}} > 0$ and $\frac{\P f^*}{\P \mathrm{d}} < 0$.

b) When *j* tends to 0 and *k* tends to 1, (almost) all the environmental damage in both countries comes from emissions generated abroad. Hence, increasing *d* will have (almost) no effect on the marginal damages of domestic emissions, but will affect those of foreign emissions. From

[16] Exactly which differences between *j* and *k* will be enough for case a) or b) to apply will depend on the difference between *d* and d.

the point of view of the welfare of the Home Country, this will require the Foreign Country to reduce its emissions (from (9b)), and the reduction in industry output below the level maximising industry profits that will result will be compensated with an increase in domestic production. By continuity, the same effects should take place as long as j is sufficiently small compared to k. Thus, when *j is sufficiently small compared to k*, we have $\frac{\partial e^*}{\partial d} > 0$ and $\frac{\partial f^*}{\partial d} < 0$; by symmetry it must then be $\frac{\partial e^*}{\partial \delta} < 0$ and $\frac{\partial f^*}{\partial \delta} > 0$.

c) When $j = k$, domestic and foreign emissions have exactly the same marginal effects on each country's welfare. Thus an increase of the domestic damage parameter d will also have exactly the same marginal effect on each country's marginal damages. Thus when d increases, both the marginal abatement of the Home and Foreign country must rise, and emissions of both countries should fall. Analogous effects will take place for an increase in the foreign country's damage parameter δ. Thus when $j = k$, $\frac{\partial e^*}{\partial d} < 0$, $\frac{\partial f^*}{\partial d} < 0$ and $\frac{\partial e^*}{\partial \delta} < 0$, $\frac{\partial f^*}{\partial \delta} < 0$. This also will imply that $j > k$ is sufficient a condition for $\frac{\partial e^*}{\partial d} < 0$, $\frac{\partial f^*}{\partial \delta} < 0$ and that that $j < k$ is a sufficient condition for $\frac{\partial e^*}{\partial \delta} < 0$, $\frac{\partial f^*}{\partial d} < 0$.

d) Case a) and c) together imply that when *$j > k$ but is not sufficiently large compared to k for satisfying case a)*, we will have again $\frac{\partial e^*}{\partial d} < 0$, $\frac{\partial f^*}{\partial d} < 0$; and $\frac{\partial e^*}{\partial \delta} < 0$, $\frac{\partial f^*}{\partial \delta} < 0$.

e) Similarly case b) and c) together imply that when *$j < k$ but is not sufficiently small compared to k for satisfying case b)*, we will have again $\frac{\partial e^*}{\partial d} < 0$, $\frac{\partial f^*}{\partial d} < 0$; and $\frac{\partial e^*}{\partial \delta} < 0$, $\frac{\partial f^*}{\partial \delta} < 0$.

Reasoning along the same lines, we would expect that

a) $\frac{\partial e^*}{\partial j} < 0$ for j big enough and d bigger or not too small compared to δ;

b) $\frac{\partial e^*}{\partial k} < 0$ for k big enough and δ bigger or not too small compared to d.

The rationale behind a) is that it is efficient to set stricter emission limits for a country the more the emissions of such country contributes to the overall damages. Thus when j and d are very small, the damages suffered by the Home Country are small and mostly due to transboundary pollution. Thus it is more efficient to allow the output of the Home Country to expand and concentrate pollution abatement on the Foreign Country, which have higher marginal damages. An analogous explanation applies to b).

2.5 Harmonisation and Emission Ceilings.

Ulph (1997) discusses extensively the idea that a supra-national authority like the European Commission uses harmonisation or "minimum" standards[17] policy as remedies to eco-dumping practices on the part of the regulated countries.

The rationale in terms of trade liberalisation for the first option is self-evident: no scope for hidden barriers is left if everybody has to abide to the same environmental requirements. However this may not be a sensible option when the countries differ widely in their environmental situation: there is no need to impose heavy emission taxes, for instance, in an untamed natural area[18].

The idea behind the emission ceiling suggestion, on the other hand, is that if some countries have to toughen their policy in order to meet those requirements, this might give rise to a ratchet effect whereby other countries will find it optimal to toughen their own policy in response. It turns out, however, that whether this ratchet effect will or will not take place depends on the shape of the countries' reaction functions.

Ulph finds little support in his model for harmonisation policies, none at all for minimum standards policies in the case of environmental standards, and some support for the latter policy in the case of taxes.

We will show that these findings do not carry over to the case of harmonised environmental standards in presence of transboundary pollution. We will illustrate our arguments by means of a diagrammatic exposition and some numerical simulations. Also we will not analyse in detail the emission ceiling option. In fact it can be shown that our additional hypotheses do not affect Ulph's conclusion that such policy is always detrimental in the case of standards.

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[17] Ulph's use of terminology is a bit confusing, as he sometimes refers to the *maximum* emission level allowed by the European Commission as "*minimum* standards" in order to be able to use the same taxonomy both for taxes and standards. Since we are not considering taxes here, we can avoid this further source of confusion by referring to Ulph's "minimum standards" case as maximum emission standards or emission ceiling.

[18] This point has been stated formally in Rauscher (1994).

This result hinges on the slopes of the countries' reaction functions, which are unaffected by our hypotheses.

The issue of the opportunity of harmonised policy can be more precisely formulated as follows: what is the maximum degree of asymmetry between the two countries' damage parameters for which setting the emissions standards at the same level in the two countries will yield to them at least the same welfare level as in the non co-operative equilibrium?

Suppose that the co-operative solution cannot be implemented. Suppose also that, although the Commission cannot force each country to take their counterpart's welfare into account, it can determine the emission standards to be imposed in each country: more specifically, it can impose the rule $e = f = E$. In order to answer the question above, Ulph asks a more specific one: if the EC chooses E in order to maximise the welfare of the country with the lower damage costs, up to which value of its own damage parameter will the high damage cost country be still better off ? Notice that in this case the EC will choose E to maximise one country's welfare, and not the co-operative objective function. This is natural, because the whole idea is that harmonization policies are to be regarded as second-best options when the co-operative equilibrium is unfeasible.

Define as $\overline{V}(E, \Delta) = V(E, E, \Delta)$ the welfare function under harmonised policy for a country with damage cost parameter Δ. To fix ideas let the Foreign country be the one with the lower environmental damage costs. Let $E^*(\text{d}) = \underset{E}{\text{Argmax}}\, V(E, E, \text{d})$ be the harmonised standard which maximises the welfare of the Foreign Country. Graphically (in Figures 3a and 3b) the point $[E^*, E^*]$ lies at the tangency between the Foreign Country's isowelfare contour and the 45° degrees line. Under harmonisation this country will thus attain at most the welfare level $\overline{V}(\text{d}, j, k) = V[E^*(\text{d}) E^*(\text{d}), \text{d}, j, k]$, for given values of j and k.

We must now determine the maximum degree of asymmetry between damage costs for which the harmonised policy still dominates the non co-operative equilibrium. To this purpose, let $\overline{d}(\text{d}, j, k)$ be the value of Home Country damage parameter for which $\hat{V}(\text{d}, \overline{d}, j, k) = \overline{V}(\text{d}, \overline{d}, j, k)$, that is, the value of the Home Country's parameter for which the harmonised policy yields the same welfare as the non co-operative equilibrium. Since $\frac{\text{d}V^H(e, f, d)}{\text{d}d} < 0$ and $\frac{\text{d}V^F(e, f, d)}{\text{d}d} > 0$, increasing $\overline{d}$ any further will make the Home Country worse off and the Foreign Country better off. In other words,

$\forall d > \overline{d}$, $\hat{V}(\mathrm{d}, d, j, k) > \hat{V}(\mathrm{d}, \overline{d}, j, k) = \overline{V}(\mathrm{d}, j, k)$ so that, $(\overline{d} - \mathrm{d})$ is the maximum value by which the Home Country's damage parameter can exceed the Foreign Country's one, before harmonisation (i.e. staying at $\overline{V}$) makes the latter worse off.

This situation is illustrated in Figures 3a and 3b where it is also shown the effect of the introduction of transboundary pollution. Solid curves and lines depict the situation described by Ulph, and broken lines depict the effect of transboundary pollution.

Recall that increasing transboundary pollution shifts out the reaction function of the two countries, and lowers their welfare. Since $\hat{V}_2(\hat{f}, \hat{e}) < 0$, a decrease in the Foreign Country's welfare in the non co-operative equilibrium can be represented in the space (*f,e*) by associating higher isowelfare contours to an increase in *k*. It is not clear, however, what will be the cumulated effect of a decrease in *j* and an increase in *k* on the welfare function, but it is reasonable to assume that, for values of *k* high enough, the effect of the latter prevails, and thus the Foreign Country's welfare will decrease.

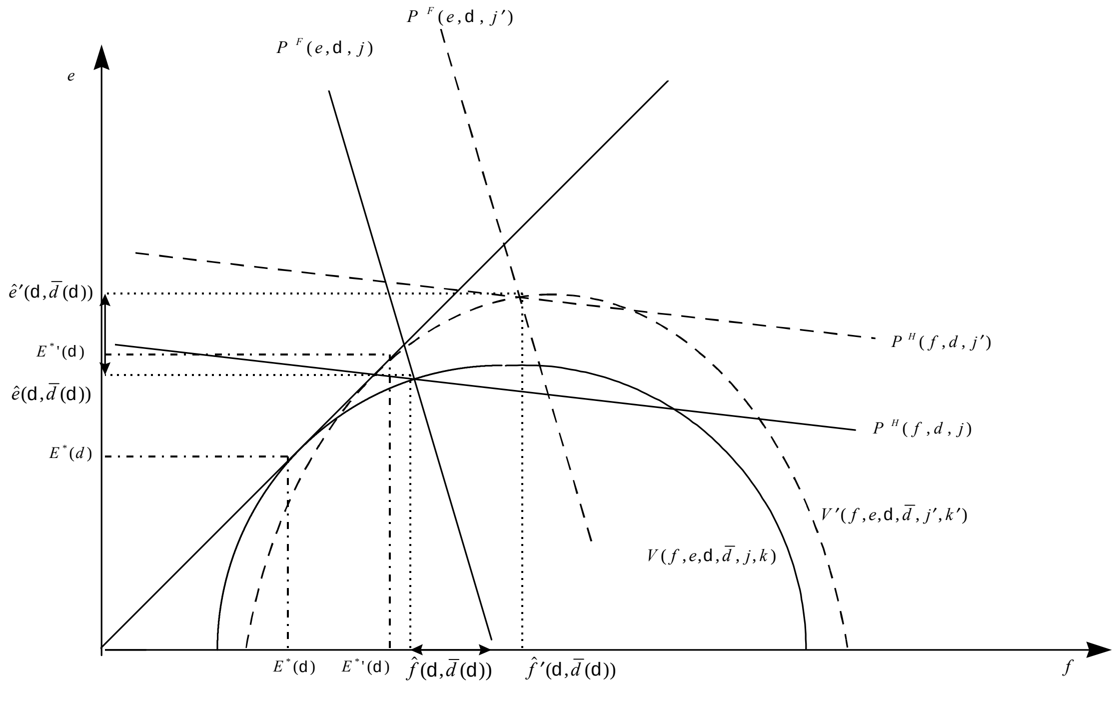

Figure 3a. Harmonisation. A decrease from *j* to *j* and an increase from *k* to *k* .

Both figures show that transboundary pollution increases the scope for harmonisation. In Figure 3a, which depicts a mild decrease in *j* and a mild increase in *k*, the harmonised policy

$\left[E^{*'}, E^{*'}\right]$ after the changes in *j* and *k*, gets equivalent to an equilibrium where $\hat{f}$ and $\hat{e}$, and hence d and d are more different[19]. This must happen because the reaction functions can intersect the isowelfare contours of the Foreign country only to the right of the 45° degrees line, on a path that must diverge from that line as the impact transboundary pollution on the damage function gets more important[20].

It can also happen that, as shown in Figure 3b, for very low values of *j*, the reaction functions could be so much shifted outwards that a harmonised policy will dominate the non co-operative equilibrium for any degree of asymmetry between d and d. In terms of Figure 3b, the non co-operative equilibrium will lie on an isowelfare contour higher than any of the ones compatible with a harmonised policy. Moreover, assuming that the direct effect on welfare of the reduction in environmental damages brought about by the decrease in *j* prevails, the point $\left[E^{*'}, E^{*'}\right]$ will lie on a lower isowelfare contour.

When the EC chooses E to maximise the welfare of the country with low damage costs, up to a certain degree, the high damage country may favor this seemingly partial choice of the EC. In fact, the Commission bases his choice of E, that is the emission limit imposed to both countries, on the environmental damages of the country with less environmental problems.
Consider first the case of *no transboundary pollution* (broken lines in Figures 3a and 3b). In general, this policy results in a reduction in the emissions of both countries[21], compared to the non cooperative equilibrium, and it is beneficial as long as the reduction in aggregate damages compensates the profits lost due to the changes in market shares. These changes will affect in particular the low damage cost country, because it has to cut its production more than its counterpart[22].

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[19] As indicated by the arrow tipped segment in Figures 3a and 3b. Its length is the distance between the Home Country's standards $\|\hat{e}' - \hat{e}\|$.

[20] Due to the concavity of the welfare function and the fact that $\left(\bar{d} > \text{d}\right)$ the reaction function can only intersect each other and the isowelfare contour in a point to the left of the 45° line where the slope of the contour is less than 45°degrees.

[21] In the non cooperative equilibrium, the reaction function can only intersect each other in a point to the left of the 45° line (see previous footnote). When d is not too high, this will happen above the level of the harmonized standard. However, for very high values of d it might in principle involve less stringent standards for the high cost country (the Home Country in this case) than under the non-cooperative equilibrium. Analytically, the first order condition of harmonization problem implies that the harmonized standard must satisfy $A' = \text{d}D'(E) - R_2\left(X_1 + X_2\right)$, which is a stricter requirement for the low cost country than the one holding in the non cooperative equilibrium, because the extra term $-R_2X_1$ is positive. This, however does not guarantee that it is also stricter for the Home Country: it might not for high values of d.

[22] Actually, in relative terms, the high damage cost country's market share will increase. This does not, however, necessarily imply an increase in its profits. When d is much larger than d, the high damage cost market share may increase also in absolute terms due to the less strict emission standards. In this case, harmonization is of course still less attractive for the low cost country.

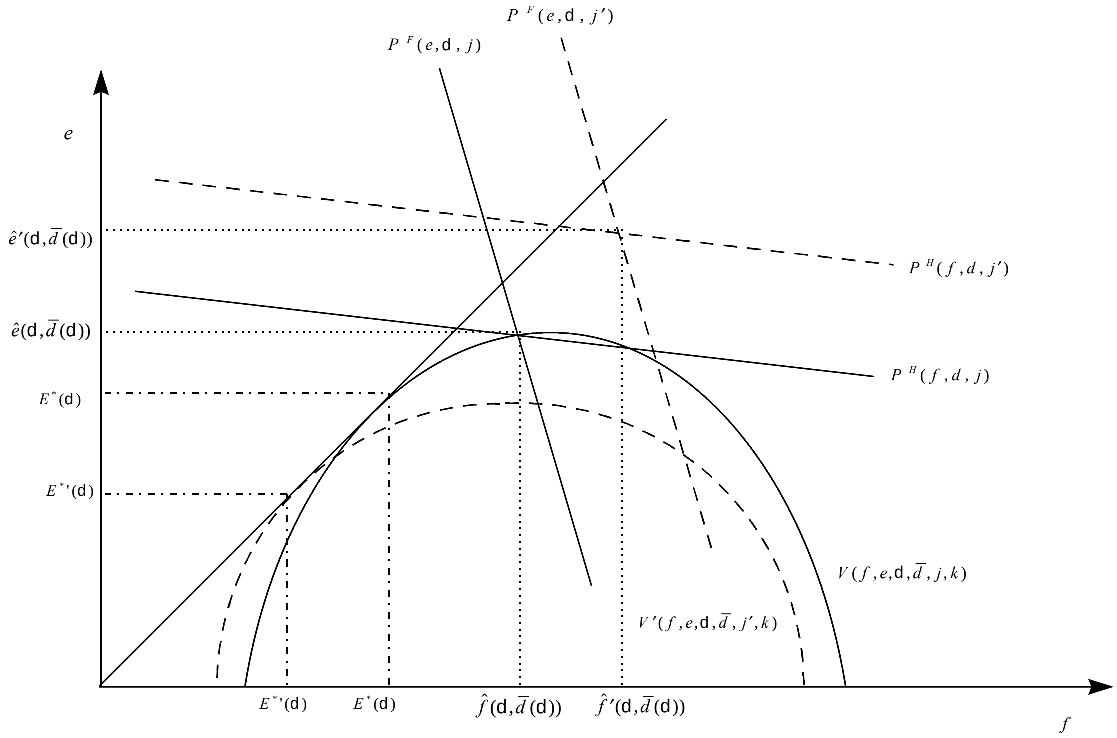

Figure 3b. Harmonisation. A decrease from *j* to *j* .

Thus this policy is likely to be more beneficial the less different are the two countries' damage costs (and hence, the smaller are the necessary adjustments in the market shares)[23].

When *transboundary pollution* is considered, the argument about the opportunity of harmonization is reinforced by the fact that the Commission can now intervene on that part of emissions that is outside the reach of each government in the non-co-operative equilibrium. Assuming again that the country with lower damage costs is the foreign one, the problem for the EC under harmonization is now to choose that common level of emission *E* that maximizes $V(E, E, \Delta, j, k) = \Pi(E, E) - \mathrm{d}\left[D(jE) + D(kE)\right]$ and that must then satisfy the condition, $\Pi_1 + \Pi_2 - \mathrm{d}\left[jD'(jE) + kD'(kE)\right] = 0$. This condition implies that also the fraction of emission causing damages to the other country, namely *kE*, is now taken into account, and this can generally lead to welfare improvements for both countries.

[23] Choosing E to maximise the welfare of the country with low damage costs is indeed the most reasonable way of formulating a harmonization policy. The low damage cost country is, in fact, the one that has more to lose from a harmonization policy. Maximizing the welfare of the country with high damage costs results in a more substantial emission reduction than in the opposite case. Under such a policy the country with low damage costs will be required a stronger abatement effort, will undergo a more substantial cut in its market share, while its welfare is not directly taken into account, and will hardly have a reason to accept harmonization.

These insights are confirmed by our numerical example. For this simulation we have relied upon the same assumptions used by Ulph for the same purpose and namely:

$$R(x,y) = (10-x-y)x;\ R(y,x) = (10-x-y)y; \qquad (10a)$$

$$C(x)= C(y)=0;\ A(x-\bar{e})= (x-\bar{e})^2/2;\ A(y-\bar{f})= (y-\bar{f})^2/2; \qquad (10b)$$

$$d[D(je)+ D(kf)]= d\,\frac{(je)^2+(kf)^2}{2};\ \mathsf{d}[D(jf)+D(ke)]= \mathsf{d}\,\frac{(ke)^2+(jf)^2}{2} \qquad (10c)$$

Fixing the Foreign Country's damage parameter[24] to d = 1, the following values for $\bar{d}(1,j,k)$ can be computed for different values of *j* and *k*:

j \ ***k***	**0**	**0,1**	**0,15**	**0,2**	**0,25**	**0,3**	**0,4**	**0,5**	**0,6**	**0,7**	**0,8**	**0,9**	**1**
0,01	1363,2	1398,5	1442,4	1503,2	1580,4	1673,2	1902,5	2184,1	2510,9	2875,7	3272,6	3696	4096
0,1	14,85	15,21	15,65	16,26	17,04	17,98	20,29	23,13	26,43	30,11	34,12	38,4	
0,15	7,29	7,45	7,64	7,92	8,27	8,69	9,73	11	12,48	14,14	15,95		
0,2	4,64	4,73	4,84	5	5,2	5,44	6,03	6,76	7,6	8,55	9,58		
0,25	3,41	3,47	3,54	3,64	3,77	3,93	4,31	4,79	5,34	5,96			
0,3	2,74	2,78	2,84	2,91	3	3,11	3,38	3,72	4,11	4,55			
0,4	2,08	2,1	2,13	2,17	2,23	2,29	2,45	2,65	2,88				
0,5	1,77	1,79	1,81	1,83	1,87	1,91	2,02	2,15					
0,6	1,6	1,61	1,63	1,65	1,67	1,7	1,78						
0,7	1,5	1,51	1,52	1,53	1,55	1,57							
0,8	1,43	1,44	1,45	1,46									
0,9	1,38	1,39											
1	1,35												

Table 2. Simulation Results for Harmonisation.

From Table 2, it transpires that the effect of transboundary pollution is substantial. Ulph's result looks more like an exception than the rule in this case.

Consider the first column. Notice how fast the maximum level of asymmetry rises from the value computed by Ulph (35%) here shown for *j* = 1 and *k* = 0, as *j* decreases. In the first column *k = 0* and thus this happens strictly for anti-dumping concerns; that is, no environmental externality is imposed by the Home Country on the foreign one. As *j* decreases, the environmental damages caused by domestic emissions is softened in both countries, and therefore the increase in emissions in the Home Country brought about by harmonisation will have a lower impact on the welfare of that country. Intuitively, this can be explained as follows: assume *k* = 0 and start with the Ulph's case *j* = 1. Decreasing *j* means that the effective difference in the damage parameters $j[\bar{d}-1]$ becomes smaller so that $\bar{d}$ can take higher values before harmonisation is no longer beneficial for the two countries.

[24] In this way $[\bar{d}(1,j,k)-1]$ can be regarded as a percentage increase on d.

Consider now the other columns. As *k* increases, this effect is reinforced by the direct negative externality that the Home Country causes to the Foreign Country and vice versa. For each value of *j*, the maximum degree of asymmetry increases as *k* increases. For high values of *k* and low values of *j*, there is virtually no limit to the degree of asymmetry tolerated. The reason is very simple: in this case both countries are doing very little effort to curb their own emissions, because these are now mainly their neighbours' problem. However they are now also, among their counterpart's neighbours, those more affected by their counterpart's emissions. And they are completely helpless towards them. Therefore they will be very happy to see enforced a harmonised policy, which can tackle both problems (i.e. the effect of their own emissions on their own welfare and the effect of the other country's emissions on their welfare) albeit in a very imperfect way[25].

2.6. Asymmetric Information.

In his model without transboundary pollution, Ulph concluded that, under complete information there was very limited scope for harmonised policies. This led him to seek an alternative rationale for such policies, and he suggested that the presence of asymmetric information may play an important role. Intuitively, when the Commission cannot tell precisely apart a country with serious environmental problems from a country with mild ones, then it may be forced to use similar instruments for different countries[26]. However, we have just shown that transboundary pollution is indeed a good reason for implementing harmonised policies. It will be interesting then to investigate whether or not asymmetric information still plays an important role under transboundary pollution.

Ulph briefly discusses also whether asymmetric information with respect to the environmental damage parameters is a real issue in this problem. He points out that local environmental problems are generally better understood locally both in their ecological characteristics and in the local inhabitants attitude towards them. We would like also to add

[25] Considering consumers' surplus has a very limited impact on the opportunity of introducing harmonization policies. If anything, it will make them slightly less desirable. Intuitively, this happens because the effect of *d* on production is indirect and negative: higher damage costs call for less emissions and hence less output. As the weight given to consumers' surplus increases, the importance of consumption and hence of production increases as well. Since increases in *d* hinder production, harmonization remains beneficial for both countries only for lower values of $\bar{d}$, compared to the situation where consumers' surplus is not considered.

[26] We will discuss later to what extent this can be regarded as "harmonization".

that one has to bear in mind that even the information that is "widely available" has been, as a rule, collected locally, and generally as a support to the local environmental policy. Thus, we cannot exclude that asymmetric information issues will influence this common information as well, in the sense that local governments can chose what to let the rest of the world know about their environmental situation.

Ulph argues that if asymmetric information is the reason why a co-operative solution cannot be imposed by the Commission this must be concluded directly in a model of asymmetric information. Also, it is within such a framework that we should discuss whether or not the European Commission's ruling will then result in a more harmonised policy. We will reiterate Ulph's analysis under our hypotheses.

The fact that the damage cost parameters are now private information, will matter also for the non co-operative equilibrium, transforming it in a game with symmetric but incomplete information. For the sake of comparison, we will reformulate the symmetric information results for the case in which the damage parameters can take two values only (either high *C*ost or low *c*ost).

2.6.1 Full Information Reconsidered

We start by characterising the equilibrium solutions under full-information in the special case in which the environmental damage parameter can take only two values, in order to make them comparable with the asymmetric equilibria, which will be analysed under that hypothesis.

Suppose then that each country's environmental damage cost parameter (*d,* d) can either be high C or low c, obviously with $C \geq c$. It is important to note that this implies that the distinction between Home and Foreign Country in the non co-operative case becomes immaterial: the solution will consist of the standards set in one country when both have high damage costs, when both have low damage costs, when the first country has low damage cost and the has other high damage cost, and finally when the first country has high damage cost and the other low damage cost. This can be shown by formulating the co-operative equilibrium problem in terms of C and c and maximising for $e(C,C)$, $e(c,c)$, $e(C,c)$ and $e(c,C)$. It is then easy to show that, in the non co-operative case, that the ranking is

$$\hat{e}(C,c,j) < \hat{e}(C,C,j) < \hat{e}(c,c,j) < \hat{e}(c,C,j) .$$

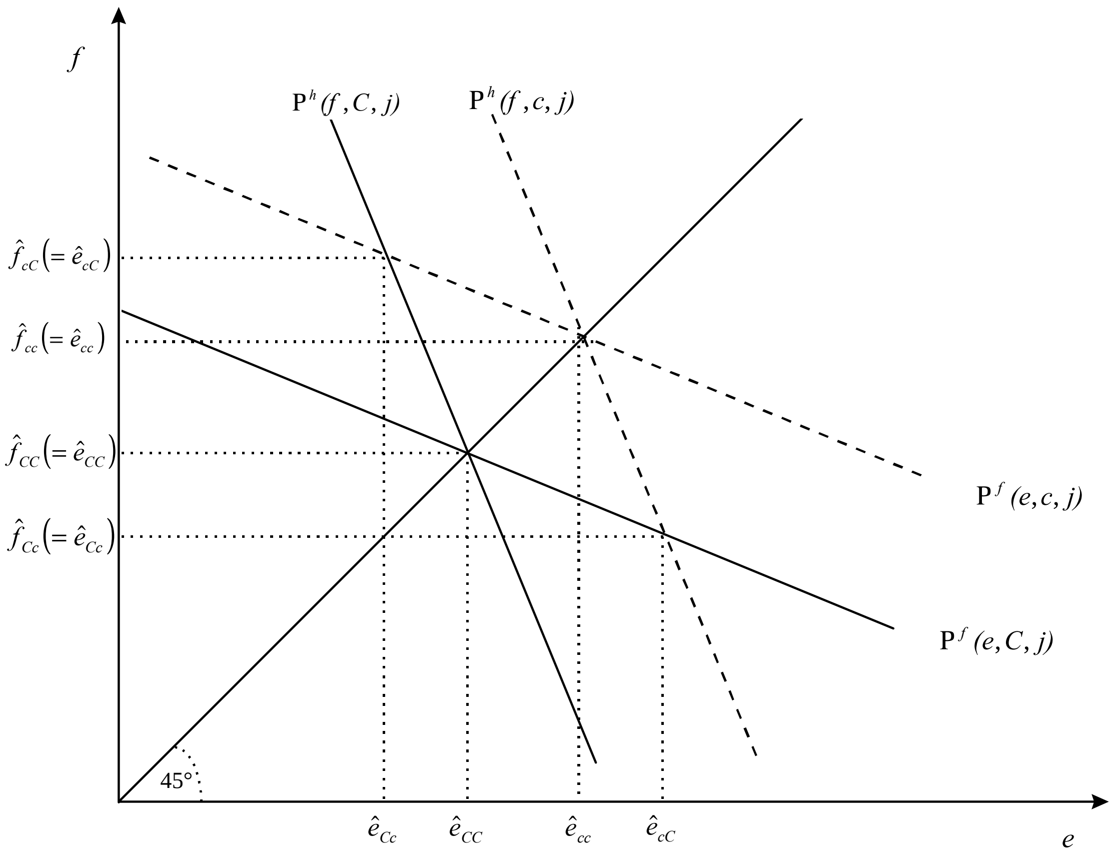

Figure 4. Ranking of standard in the Non Co-operative case.

Consider in fact Figure 4. Recall that $R_2 < 0$ (see (5)), and thus the reaction function of a country with damage parameter C must lie below and on the left of the one of a country with damage parameter c. Moreover, when both countries have the same damage parameter, they are identical and hence the equilibrium must lie on the 45°degrees line. Note also that the ranking above holds for any value of j and k.

On the other hand, j and k do influence the ranking of standards in the co-operative case. In fact we have the following

Proposition 1: In the co-operative equilibrium, in presence of transboundary pollution and under perfect information, the ranking of emission standards are:

a) when *j is large enough compared to k*,

$$e^*(C,c,j,k) < e^*(C,C,j,k) < e^*(c,c,j,k) < e^*(c,C,j,k)$$

b) when *j is small enough compared to k*,

$$e^*(c,C,j,k) < e^*(C,C,j,k) < e^*(c,c,j,k) < e^*(C,c,j,k)$$

c) when $j = k$,

$$e^*(C,C,j,k) < e^*(C,c,j,k) = e^*(c,C,j,k) < e^*(c,c,j,k).$$

d) when j is not too different from k,

$$e*\left(C,C,j,k\right) < e*\left(C,c,j,k\right) \gtrless e*\left(c,C,j,k\right) < e*\left(c,c,j,k\right).$$

Proof: See Appendix A.

These results are a straightforward application of the proprieties of the co-operative equilibrium standard discussed in subsection 2.4.2. Notice that when the two countries have the same damage costs no asymmetry is left between them, and thus it is impossible to tell them apart and treat them differently. This implies that in general there are actually three independent regulation problems here: one in which both countries have high damage cost parameters, one in which both countries have low cost damage parameters and the mixed case in which the damage costs of the two countries are different. When $j = k$ the effect of a country's emissions on overall welfare is the same as the effect of the other country's emissions even when their damage costs not the same, and thus they are again treated equally. Finally the ranking is incomplete in case d) because in that case the mentioned proprieties cannot help us to tell apart the effect on each country's emission standards, when their damage cost differ. Intuitively, however, we do not expect too much difference from case c), where $j = k$ and emission standards are the exactly same when damage costs differ. Thus, whatever their relative order, we expect very similar emission standards to be applied in this equilibrium when one country damages are high and the other country's damages are low.

2.6.2. Asymmetric Information. Non co-operative equilibrium.

Suppose that each country has to set its own standards independently, without being sure whether the other country has an high or a low damage cost parameter. However, countries are identical in every respect except the damage parameter, and thus each country is sure that the probability that the other country's damage parameter is c, is exactly the same as the probability that its own parameter is c. Let this common probability[27] be *Prob.(d = c) = Prob.(*d *= c)= p*. This transforms the game in a game of symmetric but incomplete information, which calls for Harsanyi's Bayesian-Nash equilibrium solutions.

[27] This assumption is obviously a rough approximation of the reality, and it is made to keep the analysis of asymmetric information as much as possible tractable and intuitive. However the probability *(1-p)* can be interpreted as the commonly held belief about the chances of malfunctioning of abatement technologies, or the number of days per year in which high atmospheric pressure does not allow the normal dispersion of pollutants and their concentration increases in a small area near the plants; or, for instance in case of nuclear or hydropower generation, it can be seen as the probability of a catastrophic event. Under this interpretation, typically *(1-p)* will be extremely low and *C* extremely high.

Each country sets its own emissions standards contingent on his own damage cost parameter, to maximise its expected welfare, where expectations are taken with respect to *Prob.(Q | g)* i.e. the probability that the other's country damage cost parameter is *Q* given that its own parameter cost is *g* where *Q = C,c* and *g = C, c*. Given the hypotheses above about *Prob.(d=c)* and *Prob.(d = c),* it is quite apparent that in this setting, *Prob.(Q | g)= Prob.(Q)*. Thus, the home country chooses $\ddot{e}_C$ to maximise

$$V_C = (1\text{-}p)V(\ddot{e}_C,\ \ddot{f}_C,\ C, j) + pV(\ddot{e}_C,\ \ddot{f}_c, C, j) \qquad (11a)$$

and $\ddot{e}_c$ to maximise

$$V_c = (1\text{-}p)V(\ddot{e}_c,\ \ddot{f}_C, c, j) + pV(\ddot{e}_c,\ \ddot{f}_c, c, j); \qquad (12a)$$

whereas the foreign country chooses $\ddot{f}_C$ to maximise

$$U_C = (1\text{-}p)V(\ddot{f}_C, \ddot{e}_C,\ C, j) + pV(\ddot{f}_C, \ddot{e}_c, C, j) \qquad (11b)$$

and $\ddot{f}_c$ to maximise

$$U_c = (1\text{-}\ p)V(\ddot{f}_c, \ddot{e}_C, c, j) + pV(\ddot{f}_c, \ddot{e}_c, c, j). \qquad (12b)$$

These four problems yield four first order conditions that must be solved simultaneously in order to determine the equilibrium values of the four standards. However, before determining the values of the damage parameters, we must take into account that the two countries are identical and face the same uncertainty in deciding upon their emission limits, and thus we can consider the symmetric equilibrium where $\ddot{e}_C = \ddot{f}_C$, and $\ddot{e}_c = \ddot{f}_c$ [28]. In a symmetric equilibrium the four first order conditions collapse to the following two:

$$(1\text{-}p)V_1(\ddot{e}_c, \ddot{e}_C, c, j) + pV_1(\ddot{e}_c, \ddot{e}_c, c, j) = 0 \qquad (13a)$$

$$(1\text{-}p)V_1(\ddot{e}_C, \ddot{e}_C,\ C, j) + pV_1(\ddot{e}_C, \ddot{e}_c, C, j) = 0 \qquad (13b)$$

We will now compare the equilibrium emission limits with those found under perfect information in the non co-operative case. We have the following

[28] Note that each country is now unable to know the other's type and hence it has to set the same emissions standards when its counterpart has low damage costs as when it has high damage costs. Each country, however can vary its standards according to its own damage cost parameter, and hence can count on two equilibrium levels of standards. Since the only characteristic that varies *ex-post* between the two countries is the damage cost parameter, these equilibrium standards will be exactly the same for both countries.

Proposition 2. In the non co-operative equilibrium, the equilibrium values of standard under incomplete information can be ranked against those holding under complete information as follows: $\hat{e}_{Cc} < \ddot{e}_C < \hat{e}_{CC} < \hat{e}_{cc} < \ddot{e}_c < \hat{e}_{cC}$.

Proof: see Appendix B.

Consider the case in which a country (e.g. the Home Country) has low damage costs. Under incomplete information, its government has only one instrument to tackle two different problems: the one in which the Foreign Country damage cost is also low, and the one in which the Foreign Country damage cost is high. Intuitively, the best policy the Home government can choose in such a situation must end up somewhere in between the two ones it would have chosen if a better information would have allowed it to tackle these two problems separately. When the Home Country damage costs are high, its government finds itself in the same situation, and the best it can do under incomplete information is again to use a single instrument to mediate between two different problems. Finally it should be clear that, since under incomplete information the only safe information a government can base its policy on is the damage cost of its own country, it will set stricter emission standards when domestic damage costs are high than when they are low.

Moreover, after subtracting $\hat{e}_{Cc}$ from the ranking in Proposition 2, Ulph notes that

$$0 = \hat{e}_{Cc} - \hat{e}_{Cc} < \ddot{e}_C - \hat{e}_{Cc} < \hat{e}_{CC} - \hat{e}_{Cc} < \hat{e}_{cc} - \hat{e}_{Cc} < \ddot{e}_c - \hat{e}_{Cc} < \hat{e}_{cC} - \hat{e}_{Cc}. \qquad (14)$$

This implies $\ddot{e}_c - \hat{e}_{Cc} < \hat{e}_{cC} - \hat{e}_{Cc}$. Since $\hat{e}_{Cc} < \ddot{e}_C$, it follows that $\ddot{e}_c - \ddot{e}_C < \hat{e}_{cC} - \hat{e}_{Cc}$. In words, asymmetric information leads the governments to set environmental standards, when damage parameters differ, less wide apart than under full information.

Finally, the results above are independent from the values of *j* and *k*[29].

2.6.3. Co-operative equilibrium.

Suppose now that the two countries delegate the power of determining their joint environmental policy to the European Commission and that the latter is unable to know the countries' damage cost parameter with certainty. It will be aware, however that, as before, *Prob.(d = c) = Prob.(D = c)= p*. The Commission will then behave as the principal in a simple adverse selection principal-agent model, and the two countries will be the regulated

[29] They hinge on proprieties of the equilibrium and of the welfare functions that do not depend on these parameters. See Appendix B.

agents. The game is now a three stage[30] incomplete and asymmetric information game with five players. In the first stage, the two governments declare their damage cost parameters to the Commission. In the second stage, “each country will be assigned an appropriate emission standard” by the Commission contingent on the declared types. In the third stage, firms compete *à la* Cournot.

The Commission aims at inducing truthful revelation of the damage cost parameter on the part of the two governments. In general, it will try to do so by setting the standards in a way that discourages misreporting.

We will show that the incentive for a country to misreport depends on *j* and *k*. Generally speaking, each country will try to obtain from the Commission the permission to discharge high levels of emissions, thus increasing the market share of the national production in equilibrium, and hence profits and national welfare.

The Commission will use a financial transfer *M* and four levels of the environmental standards in order to maximise the expected aggregate welfare of the two countries in a way compatible with truthful revelation of their types: e_{CC} when both countries report a high damage parameter, e_{cc} when both countries report a low damage parameter, e_{Cc} and e_{Cc} respectively when one country reports a high damage parameter, and the other a low one.

The way the objective function is formulated in Ulph’s paper is not self-evident, and it can be illustrated with the help of the following table:

Home Country				**Foreign Country**				**Joint Probability of the state of the world**
Actual Damage	**Declared Damage**	**Probability of opponent s declaration**	**Welfare**	**Actual Damage**	**Declared Damage**	**Probability of opponent s declaration**	**Welfare**	
C	*C*	*1-p*	*V(eCC, eCC, C)*	*C*	*C*	*1-p*	*V(eCC, eCC, C)*	*(1-p)²*
C	*c*	*1-p*	*V(ecC, eCc, C)*	*C*	*c*	*1-p*	*V(ecC, eCc, C)*	*0*
C	*C*	*p*	*V(eCc, ecC, C)*	*C*	*C*	*p*	*V(eCc, ecC, C)*	*p(1-p)*
C	*c*	*p*	*V(ecc, ecc, C)*	*C*	*c*	*p*	*V(ecc, ecc, C)*	*0*
c	*C*	*1-p*	*V(eCC, eCC, c)*	*c*	*C*	*1-p*	*V(eCC, eCC, c)*	*0*
c	*c*	*1-p*	*V(ecC, eCc, c)*	*c*	*c*	*1-p*	*V(ecC, eCc, c)*	*p(1-p)*
c	*C*	*p*	*V(eCc, ecC, c)*	*c*	*C*	*p*	*V(eCc, ecC, c)*	*0*
c	*c*	*p*	*V(ecc, ecc, c)*	*c*	*c*	*p*	*V(ecc, ecc, c)*	*p²*

Table 3. The States of the World.

To understand Table 3, keep in mind that this table lists all the conceivable states of the world, and consider, for instance the first row. In that row it is shown what happens when the two countries have both high damage costs, and both expect their opponent to report high

[30] Actually there is a stage zero in which Nature assigns each country its type and the latter learns it.

damage costs[31]. The first half of the row depicts the situation from the point of view of the Home Country, and the second half of the row depicts the situation from the point of view of the Foreign Country. Now, the Home Country expects that the other country will have high damage costs with probability *(1-p)*. The same expectations will be held by the Foreign Country with respect to a truthful report on the part of the Home Country when the latter has a high damage cost. Since these events are independent, their expectations will be simultaneously fulfilled with joint probability $(1-p)^2$. An analogous argument applies to the last row, where the case of both countries reporting truthfully low damage costs is considered.

Consider now the third row. In that row it is shown what happens when the two countries have both high damage costs, and both expect their opponent to report low damage costs and both intend to report truthfully their high damage costs. Thus, they both attach a probability *p* to their opponent's damage costs. However, each country has high damage costs, and intend to report them correctly. High cost realisation happens with probability *(1-p)*. Thus each country will expect the other one to report *c* while its own report is truthful and is *C*, with probability *p(1-p)*. An analogous argument applies to the sixth row, where it is considered the case of both countries reporting truthfully low damage costs, but each of them expecting a high damage cost report from its opponent.

Consider now the remaining rows. To anticipate some results, when $j > k$, the second and fourth row could occur but have joint probability zero because the incentive constraints prevent them to take place in equilibrium; in fact they correspond exactly to the cases in which a high damage cost country misreports its type. Intuitively, these cases are those in which the Commission expects to face false reports, and hence the Commission will use its instruments to make these states of the word the less palatable possible for the governments, so that misreporting will turn out to be a dominated choice in equilibrium. The fifth and the seventh row, on the other hand, correspond to choices that are dominated from the start and will not be chosen, and thus we again indicated a zero joint probability for them. Intuitively, to report high damage costs when emissions cause mostly domestic damages and the actual damage costs are low is not very smart, because it forces the Commission to impose an unnecessarily strict environmental policy to the country making such a report, thus causing a welfare loss due to an excessive reduction in output and profits.

[31] Since also each government has incomplete information with respect to its counterpart's damages, it is unable to judge whether the report of the opponent was truthful or not. Since at this stage we are only interested in the game between the Commission on one side and the governments on the other, we assume that each government expects naively the other one to report truthfully.

When k is sufficiently large compared to j, the role of the named rows is inverted[32].

Thus, in both cases, assuming that the other country tells the truth for the reasons above, each country has an expected welfare of

$$p^2V(e_{cc},e_{cc},c)+ p(1-p)V(e_{Cc},e_{cC},C)+ (1-p)pV(e_{cC},e_{Cc},c)+ (1-p)^2V(e_{CC},e_{CC},C). \qquad (15)$$

Summing over countries and rearranging, one gets the Commission's objective function as stated by Ulph:

$$W(e_{CC}\ e_{Cc},e_{cC},e_{cc})=2\{p^2V(e_{cc},e_{cc},c)+(1-p)p[V(e_{Cc},e_{cC},C)+V(e_{cC},e_{Cc},c)]+(1-p)^2V(e_{CC},e_{CC},C)\}. \qquad (16)$$

In order to write the incentive compatibility constraints[33], it is useful to define the function

$$f\ (e_{CC}\ e_{Cc},e_{cC},e_{cc},d)= [(1-p)V(e_{cC},e_{Cc}\ d)+pV(e_{cc},e_{cc},d)]-[(1-p)V(e_{CC},e_{CC},d)+pV(e_{Cc},e_{cC},d)\ ],\ d=c,C.$$

The function f is just a compact way to represent the incentive compatibility constraints. For instance when $d = c$, the first term is the expected payoff from reporting truthfully, and the second term is the expected payoff from misreporting. Thus the constraint in this case requires a value of f larger or equal to M.

Let s be the social cost of public funds. The Commission's problem is then

$$\underset{e_{CC},e_{Cc},e_{cC},e_{cc},M}{MAX} W\left(e_{CC},e_{Cc},e_{cC},e_{cc}\right)-sM \qquad (17)$$

$$S.t.\ M \geq f\ (e_{CC}\ e_{Cc},e_{cC},e_{cc},C);$$

$$f\ (e_{CC}\ e_{Cc},e_{cC},e_{cc},c) \geq M.$$

The first constraint, as can be easily understood from table 3, signifies that the Commission has to take in account that an high damage cost country may have the incentive to pretend to be a low damage cost one in order to be assigned higher emission standard and thus an higher market share. The second constraint means that a country might have an incentive to pretend to have high damage costs when in fact it has low ones.

In order to solve problem (17) above, we have first to determine which constraint is binding, and under what conditions. We have the following:

Proposition 3. To a first order approximation, and in the absence of financial transfers:

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[32] We will show that, in the remaining cases ($j = k$ and j smaller but not too different from k) no incentive constraint is binding. In these cases both the dotted and the shaded rows will have zero probability and the problem will boil down to the cooperative equilibrium in prefect information.

[33] It must be noted also that, although Ulph writes only two incentive compatibility constraints, there are actually two pairs of identical ones, one pair for each country.

a) when $j > k$, the incentive compatibility constraints for a country with low environmental damages will be satisfied but the one for a country with high environmental damages will be violated in the full information co-operative equilibrium;

b) when *j is small enough compared to k*, the reverse will happen, and it will be the turn of the low damage cost country to face the temptation of misreporting[34].

c) no incentive constraint is binding, when *j is smaller than k*, but not too much, or when *j is equal to k*.

Proof: See Appendix C.

The reason for this pattern in the incentive constraints is the following. When $j > k$ the reported parameter has more effect on the own emission standards, and hence on the marginal costs of each country. Hence it pays to pretend to have a low damage cost parameter, in order to be assigned an higher level of emissions. On the other hand, when $j < k$, each country's report affects more its opponent's marginal damages and welfare than its own. It pays then to pretend to have high damage costs, so that the opponent will be asked to reduce its emission to protect the liar. When $j = k$, the effect is the same on both countries' marginal damages, and thus nobody has an incentive to provide distorted information to the Commission; put in another way, in this case each country cannot expect a different treatment from its counterpart, and hence there is no incentive whatsoever for false reports. Finally, it is interesting to consider what happens when *j* does not differ too much from *k*. In particular, notice the asymmetry between the case in which $j > k$, where the incentive constraint for the high cost country is always binding, and the case in which $j < k$, where no incentive constraint may be binding if the difference between the two parameters is not large enough. This happens because, in the latter case, the beneficial effects for a low cost country that falsely reports high costs, take place only indirectly, trough the reduction in the other country's output and emissions. Thus, while misreporting for the high cost country remains a dominated strategy whenever $j < k$, it takes a noticeable difference between these parameters before the indirect benefits outweigh the direct profit loss for a low cost country that falsely reports high costs.

There are six solutions to this model. The first was already present in Ulph's model, the others generalise Ulph's second and third solutions.

a) The first order approximation may not hold when there is a large difference between *C* and *c*. When $j \geq k$ [35] the following inequality may hold:

$$\text{f}\left(e^{*}_{cc},e^{*}_{Cc},e^{*}_{cC},e^{*}_{CC},c\right)\geq 0\geq \text{f}\left(e^{*}_{cc},e^{*}_{Cc},e^{*}_{cC},e^{*}_{CC},C\right). \qquad (18)$$

This implies that "the full information co-operative equilibrium can be implemented without any financial transfer".

b) As in Ulph's model, "suppose that the relevant incentive constraint is binding, but *s=0*. In words, it is costless to rise a financial transfer. Then it is always possible to find a positive financial transfer, *from the low damage cost country to the high damage cost country*, *M* such that $\text{f}\left(e^{*}_{cc},e^{*}_{Cc},e^{*}_{cC},e^{*}_{CC},c\right)\geq M\geq \text{f}\left(e^{*}_{cc},e^{*}_{Cc},e^{*}_{cC},e^{*}_{CC},C\right)$", when $j > k$. This means that it will be possible to subtract *M* from the expected welfare of a truth-telling low cost country, without making it change its mind, and, by giving the same amount to the other country, induce it to tell the truth.

On the other hand, when $j < k$, it is always possible to find a *negative* financial transfer, $T< 0$ *(with M= -T) from the high damage cost country to the low damage cost country*, such that, $\text{f}\left(e^{*}_{cc},e^{*}_{Cc},e^{*}_{cC},e^{*}_{CC},C\right)\leq T\leq \text{f}\left(e^{*}_{cc},e^{*}_{Cc},e^{*}_{cC},e^{*}_{CC},c\right)<0$. Since *T* is *negative* this amounts to say that it will be possible to subtract *T* from the expected welfare of a truth-telling high cost country, without making it change its mind, and, by giving the same amount to the other country, induce it to tell the truth. Thus in both cases "the full information equilibrium can be implemented solely by means of financial transfers."

c) When $j= k$, as shown in Appendix C, no incentive compatibility constraint is binding. Hence, for any value of *s*, *C* and *c*, the full information optimum can be implemented without financial transfers.

d) Analogously, when $j < k$, but the difference between the two parameters is small, no incentive compatibility constraint is binding. Hence, for any value of *s*, the full information optimum can be implemented without financial transfers. The maximum difference between *j* and *k* up to which this holds, depends on *C* and *c*.

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[34] In terms of Table 3, the roles of the shaded rows and those of the dotted rows are inverted.

[35] On the other hand, when *j is small enough compared to k*, a large differences between *C* and *c* can only reinforce the incentive for the low cost country to pretend to be an high cost one, and it makes less attractive the reverse. In fact in the full information equilibrium, a country with very low environmental damages cost will suffer no harm from pretending to be an high cost one, since its declaration will, to the largest extent, affect the other country. On the other hand pretending to be a low cost one when having actually high will simultaneously increase the damage caused by foreign emission and reduce the market share, decidedly a dominated strategy.

e) Suppose now that $j > k$, $s > 0$ and that the difference between C and c is small enough to make the incentive compatibility constraint for the high cost country binding. Then the Commission cannot implement the full information equilibrium.

Let L be the Lagrangean of the above problem and λ and μ the Lagrangean multipliers associated with the first and second incentive constraint respectively.

Define also $\beta \equiv \dfrac{\lambda}{p(1-p)}$; then the following first order conditions and can be derived[36]:

$$\frac{\partial L}{\partial e_{CC}} = V_1(\tilde{e}_{CC}, \tilde{e}_{CC}, C) + V_2(\tilde{e}_{CC}, \tilde{e}_{CC}, C) \le 0; \quad \tilde{e}_{CC} \ge 0; \tag{19}$$

$$\frac{\partial L}{\partial e_{cc}} = V_1(\tilde{e}_{cc}, \tilde{e}_{cc}, c) + V_2(\tilde{e}_{cc}, \tilde{e}_{cc}, c) - \beta(1-p)\left[V_1(\tilde{e}_{cc}, \tilde{e}_{cc}, C) + V_2(\tilde{e}_{cc}, \tilde{e}_{cc}, C)\right] \le 0; \quad \tilde{e}_{cc} \ge 0; \tag{20}$$

$$\frac{\partial L}{\partial e_{Cc}} = V_1(\tilde{e}_{Cc}, \tilde{e}_{cC}, C) + V_2(\tilde{e}_{cC}, \tilde{e}_{Cc}, c) + \beta\left[pV_1(\tilde{e}_{Cc}, \tilde{e}_{cC}, C) - (1-p)V_2(\tilde{e}_{cC}, \tilde{e}_{Cc}, C)\right] \le 0; \quad \tilde{e}_{Cc} \ge 0; \tag{21}$$

$$\frac{\partial L}{\partial e_{cC}} = V_1(\tilde{e}_{cC}, \tilde{e}_{Cc}, c) + V_2(\tilde{e}_{Cc}, \tilde{e}_{cC}, C) + \beta\left[pV_2(\tilde{e}_{Cc}, \tilde{e}_{cC}, C) - (1-p)V_1(\tilde{e}_{cC}, \tilde{e}_{Cc}, C)\right] \le 0; \quad \tilde{e}_{cC} \ge 0; \tag{22}$$

$$\frac{\partial L}{\partial M} = -s + \lambda \le 0; \quad \tilde{M} \ge 0; \tag{23}$$

f) Suppose now that j is small enough compared to k, $s > 0$ and that the difference between C and c is small enough to make the incentive compatibility constraint for the low cost country binding. Again the Commission cannot implement the full information equilibrium.

Let $\gamma \equiv \dfrac{\mu}{p(1-p)}$ and $M = -T$ (with $T < 0$)[37]. The first order conditions become:

$$\frac{\partial L}{\partial e_{cc}} = V_1(\tilde{e}_{cc}, \tilde{e}_{cc}, c) + V_2(\tilde{e}_{cc}, \tilde{e}_{cc}, c) \le 0; \quad \tilde{e}_{cc} \ge 0; \tag{24}$$

$$\frac{\partial L}{\partial e_{CC}} = V_1(\tilde{e}_{CC}, \tilde{e}_{CC}, C) + V_2(\tilde{e}_{CC}, \tilde{e}_{CC}, C) - \gamma p\left[V_1(\tilde{e}_{CC}, \tilde{e}_{CC}, c) + V_2(\tilde{e}_{CC}, \tilde{e}_{CC}, c)\right] \le 0; \quad \tilde{e}_{CC} \ge 0; \tag{25}$$

$$\frac{\partial L}{\partial e_{Cc}} = V_1(\tilde{e}_{Cc}, \tilde{e}_{cC}, C) + V_2(\tilde{e}_{cC}, \tilde{e}_{Cc}, c) + \gamma\left[(1-p)V_2(\tilde{e}_{cC}, \tilde{e}_{Cc}, c) - pV_1(\tilde{e}_{Cc}, \tilde{e}_{cC}, c)\right] \le 0; \quad \tilde{e}_{Cc} \ge 0; \tag{26}$$

$$\frac{\partial L}{\partial e_{cC}} = V_1(\tilde{e}_{cC}, \tilde{e}_{Cc}, c) + V_2(\tilde{e}_{Cc}, \tilde{e}_{cC}, C) + \gamma\left[(1-p)V_1(\tilde{e}_{cC}, \tilde{e}_{Cc}, c) - pV_2(\tilde{e}_{Cc}, \tilde{e}_{cC}, c)\right] \le 0; \quad \tilde{e}_{cC} \ge 0; \tag{27}$$

$$\frac{\partial L}{\partial M} = -s + \mu \le 0; \quad \tilde{M} \ge 0. \tag{28}$$

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[36] In this case and in the following one we will assume that " all the emission limits are strictly positive", but from the last condition "there will be two sub-cases: (i) where $\lambda < s$, i.e. where the social cost of funds is high and where the optimal transfer is zero; (ii) where $\lambda = s$ and the optimal transfer is positive".

[37] Note that changing the sign of the transfer does not affect the sign of the social costs of public funds, and hence the form of the last first order condition.

We can now compare he equilibrium standards in cases d) and e) with those set in the full information equilibrium. We follow Ulph in simplifying the notation by introducing the expression $h(e,f,d,d) = V_1(e,f,d) + V_2(f,e,d)$, where:

$h_1(e,f,d,d) = V_{11}(e,f,d) + V_{22}(f,e,d) = P_{11} \; -dj^2D \; (je) + P_{22} \; - dk^2D \; (ke) < 0;$ (29)

$h_2(e,f,d,d) = V_{12}(e,f,d) + V_{21}(f,e,d) = P_{12} + P_{21} = 2V_{12} \; < 0;$ (30)

(hence by assumption $h_1 < h_2 < 0$)

$h_3(e,f,d,d) = V_{13}(e,f,d) = \; -dj^2D \; (je) - kD \; (kf) < 0;$ (31)

$h_4(e,f,d,d) = V_{23}(f,e,d) = - kD \; (ke) < 0.$ (32)

First, it is immediate to see that

$$h\left(\tilde{e}_{CC}, \tilde{e}_{CC}, C, C\right) = h\left(e^*_{CC}, e^*_{CC}, C, C\right) \Rightarrow e^*_{CC} = \tilde{e}_{CC} \text{ when } j > k, \qquad (33)$$

$$h\left(\tilde{e}_{cc}, \tilde{e}_{cc}, c, c\right) = h\left(e^*_{cc}, e^*_{cc}, c, c\right) \Rightarrow e^*_{cc} = \tilde{e}_{cc} \text{ when } j \text{ is small enough compared to } k. \qquad (34)$$

This is a standard result of principal-agent theory: when both agents report what it was feared they would conceal, then the truthful revelation mechanism has worked, and the full information outcome can be implemented.

Second, consider condition (25) for case e), and notice that the term in square brackets is positive. This follows from the fact that $h(e,f,c,c) = V_1(e,f,c) + V_2(f,e,c)$ would have been zero for e^*_{cc} in the full information equilibrium. If, however both countries falsely report *C*, from the fact that $e^*_{CC} < e^*_{cc}$ and from the convexity of the objective function it follows that their reports will place their assigned emission limits on the upward sloping side of the “true” objective function. This will make the second member of that condition negative, and hence,

$$h\left(\tilde{e}_{CC}, \tilde{e}_{CC}, C, C\right) > 0 \, , \, h\left(e^*_{CC}, e^*_{CC}, C, C\right) = 0 \Rightarrow e^*_{CC} > \tilde{e}_{CC} \, , \qquad (35)$$

when *j is small enough compared to k*[38].

An analogous argument will show that in (20) for case d) the second member is positive, and hence

$$h\left(\tilde{e}_{cc}, \tilde{e}_{cc}, c, c\right) < 0, \, h\left(e^*_{cc}, e^*_{cc}, c, c\right) = 0 \Rightarrow e^*_{cc} < \tilde{e}_{cc} \text{ when } j > k. \qquad (36)$$

This happens because the Commission wants to discourage false reports and does so by making particularly harmful the consequences of a false report. Thus, when $j > k$, pretending to have low damages will result in very high emission standards for a country with actually

[38] Strictly speaking, it would have been sufficient that the emission limits of only one country had been lower under asymmetric information, but since the two countries are *ex-ante* identical and hence they must have the same standards when they make the same report.

high damage costs, that will then suffer a lot more than expected from its own emissions. When *j* is small enough compared to *k*, the punishment will consist of much smaller market shares than expected.

Finally, consider conditions (21) and (22) for case e) (that is, when $j > k$). In the proximity of the full information optimum it must be $V_1>0$ and $V_2<0$. It follows that $b\left[pV_1(e_{Cc},e_{cC},C)-(1-p)V_2(e_{cC},e_{Cc},C)\right]>0$ which implies $h(\tilde{e}_{Cc},\tilde{e}_{cC},C,c)<0$. By the same argument we have $h(\tilde{e}_{cC},\tilde{e}_{Cc},c,C)>0$. Thus we have

$$\left.\begin{array}{l} h(e^*_{Cc},e^*_{cC},C,c)=0,\, h(\tilde{e}_{Cc},\tilde{e}_{cC},C,c)<0 \\ h(e^*_{cC},e^*_{Cc},c,C)=0,\, h(\tilde{e}_{cC},\tilde{e}_{Cc},c,C)>0 \end{array}\right\} \Rightarrow \begin{cases} \text{either 1) } e^*_{Cc}<\tilde{e}_{Cc} \text{ and } e^*_{cC}>\tilde{e}_{cC} \\ \text{or} \quad \text{2) } e^*_{Cc}>\tilde{e}_{Cc} \text{ and } e^*_{cC}<\tilde{e}_{cC} \end{cases}$$

On the other hand, when *j is small enough compared to k* (case f) the same argument applied to conditions (26) and (27) yields the opposite results, and namely:

$$\left.\begin{array}{l} h(e^*_{Cc},e^*_{cC},C,c)=0,\, h(\tilde{e}_{Cc},\tilde{e}_{cC},C,c)>0 \\ h(e^*_{cC},e^*_{Cc},c,C)=0,\, h(\tilde{e}_{cC},\tilde{e}_{Cc},c,C)<0 \end{array}\right\} \Rightarrow \begin{cases} \text{either 1) } e^*_{Cc}>\tilde{e}_{Cc} \text{ and } e^*_{cC}<\tilde{e}_{cC} \\ \text{or} \quad \text{2) } e^*_{Cc}<\tilde{e}_{Cc} \text{ and } e^*_{cC}>\tilde{e}_{cC} \end{cases}.$$

The above results are derived considering first order expansions of the function h around the full information optimum. There are two main implications in these results. First, the ordering of $\tilde{e}_{Cc}$ and $\tilde{e}_{cC}$ with respect to the corresponding full information equilibrium standards when $j > k$ will be the opposite of the one holding when *j* is smaller enough compared to *k*. Second, if, as Ulph claims for his model without transboundary pollution, the rankings we have indicated with 1) holds true, "then when countries differ in their damage costs, asymmetric information means that the Commission will require the countries to have more similar emissions than would be the case with full information". If, on the other hand, the rankings under 2) hold true, countries will be required less harmonised policies than under full information.

In order to shed some light on the question of which is the relevant option between 1) and 2), and to better characterise the asymmetric information equilibria, we will use some numerical simulation, which will be presented and discussed in the next section.

2.7. Simulation results

Ulph resorts to some numerical simulations for *C* ranging from 1.2 to 3.6, using the same functional forms adopted for the numerical simulation presented in the section about harmonisation, and assuming $p = 0.5$, and $c = 1$.

We also assume *s* to be high enough to make financial transfers useless. In Ulph's simulation this happened already for very low values of *s*, and thus the resulting loss of generality in our simulations will be very limited.

Ulph presents the equilibrium values of the four standard levels e_{CC} , e_{Cc}, e_{cC} , e_{cc} for the four equilibrium settings considered, and the resulting level of expected welfare for an high damage cost country, for a low cost one, and the total expected welfare.

Numerical simulations are necessary because without solving for λ and ɱ nothing can be said about the impact of asymmetric information on the ranking of the standards in the co-operative equilibrium. This difficulty is compounded by the presence of transboundary pollution. Thus, we ran some simulations using GAMS for some values of *j* and *k* ranging from 0 to 1. This will allow us not only to retrieve Ulph's results for particular values of these parameters, but also to better characterise their effect on the equilibrium solution. Some simulation results are presented graphically in Figures 5 and 6 below.

Ulph found that, for C smaller than 2.8, the ranking is $\tilde{e}_{CC} < \tilde{e}_{Cc} < \tilde{e}_{cC} < \tilde{e}_{cc}$, which implies $\tilde{e}_{cC} - \tilde{e}_{Cc} < \tilde{e}_{cC} - \tilde{e}_{CC} < \tilde{e}_{cc} - \tilde{e}_{CC}$; that is "when the countries are asymmetric the difference between the emission of the high and low damage cost country is less than the difference in emission in the cases where both countries have either high or low damage costs". This implies, that in comparison with the full information co-operative equilibrium, in the first case standards are to a certain extent harmonised. Ulph notes that this is inefficient but can be explained in terms of truth-telling incentives. On the other hand, again due to truth-telling concerns, the standards implemented when both countries report an high damage parameter are set more widely apart from those implemented when both countries report a low one, in the asymmetric information co-operative equilibrium than in the full information one, and thus even more disparity of treatment rather than harmonisation is called for. For higher values of C, the incentive constraint is not binding and thus asymmetric and full information equilibria coincides. All these results can easily been verified for *j* =1, *k* = 0[39].

What happens when transboundary pollution considerations matter?

First, note that, as the equilibrium solutions demonstrate, *k* has no influence on the non co-operative equilibria, whatever the information setting. Also, as was shown in the previous section, incomplete information between countries acting non co-operatively prevent each of them to set standards differentiated according to its counterpart's type[40].

---

[39] Introducing consumers surplus considerations in the analysis is again almost uneventful. Ulph's conclusion are hardly affected. Increasing the weight of consumers' surplus in the Commission's objective function results in a slight increase in total welfare and emissions and in a slightly more differentiated treatment of the countries.

[40] This is of course true in the consumers' surplus case as well.

Second, when *j = k,* and for *C > 3* when *j > k*, truthful revelation is not an issue, that is the equilibrium values of the standards in the co-operative equilibria are the same under full and asymmetric information.

As a result, rankings are slightly altered by the presence of transboundary pollution, in the co-operative equilibria and are not affected at all in the non co-operative ones. We have already indicated those for the full information case in the previous section. To reiterate, when *j is small enough compared to k,* they are $e^*_{cC} < e^*_{CC} < e^*_{cc} < e^*_{Cc}$, and when *j = k,* we found that the order is $e^*_{CC} < e^*_{cC} = e^*_{Cc} < e^*_{cc}$.

On the other hand, under asymmetric information, when *j is small enough compared to k* the ranking under the second incentive compatibility constraint is $\tilde{e}_{CC} < \tilde{e}_{cC} < \tilde{e}_{Cc} < \tilde{e}_{cc}$ which implies $\tilde{e}_{Cc} - \tilde{e}_{cC} < \tilde{e}_{Cc} - \tilde{e}_{CC} < \tilde{e}_{cc} - \tilde{e}_{CC}$. The rationale behind this ranking is again the need to motivate agents to report truthfully. This is done by making very unattractive for a low cost country, which aims at being assigned high emissions, the outcome in which both reports are *C.* Notice that the more harmful is misreporting from a co-operative point of view (that is, the higher is *C*), the harder this punishment is made by setting the four standards more widely apart.

When *j is larger than k*, the ranking is $\tilde{e}_{CC} < \tilde{e}_{Cc} < \tilde{e}_{cC} < \tilde{e}_{cc}$ which implies $\tilde{e}_{cC} - \tilde{e}_{Cc} < \tilde{e}_{cC} - \tilde{e}_{CC} < \tilde{e}_{cc} - \tilde{e}_{CC}$ as in Ulph. In both cases, we can still conclude that the resulting policy looks like a harmonised one when the two countries' reports differ but a wider disparity in treatment between high and low damage cost countries than in the full information setting results when both make the same report.

It can also be said that when the two countries do not differ a lot in terms of damage costs, something very closely resembling an harmonisation policy is certainly called for, for any value of *j* and *k*. Another difference between Ulph' s base case and the general one in which *j* and *k* are allowed to vary between 0 and 1, is that it becomes more difficult for the incentive constraints to be not binding, even when *C* is very high. In fact Ulph's states that this is the case when *C* is > *2.8*; the only other values of *j* and *k* for which this holds are *j= 0.9* and *k= 0.1*, and only for *C = 3.6*. Thus, transboundary pollution seems on one hand to make truthful revelation a more serious issue, since even large disparities in the damage parameters do not discourage agents from misreporting. This is due to the mentioned fact that values of *j* less than one mitigate the effect of an high *C*. On the other hand the Commission's problem is somewhat eased when *j = k*, because then countries have no incentive to misreport.

Notice also that emission standard tend to be higher in the non co-operative and in the co-operative equilibria, when *j* and *k* are low. This is reasonable since in these cases the two countries' emissions are basically somebody else's problem, both from their individual and joint point of view. Also, in these cases their co-operative policies are much more harmonised. The reason is probably the same as above: small values of *j* and *k* tend to smooth the effect of differences in the damage cost parameters.

As to the welfare levels, countries are always better off in the co-operative equilibria rather than in the non co-operative ones. However, it can hardly come unexpected that the highest total expected welfare is attained in the full information co-operative equilibrium, since it is what, in the present framework, can be regarded as the "first best"[41].

Moreover, when the first incentive constraint is binding, a low damage cost country is better off in terms of expected welfare under full information than under asymmetric information, whereas an high damage cost one is better off in the asymmetric information equilibrium. When the second incentive constraint is binding, the reverse holds. This again can be explained in terms of truthful revelation incentives: in the asymmetric information outcome the expected payoff for misreporting has to be not higher, for the players more likely to misreport than the payoff for truthful revelation. This is precisely what the incentive compatibility constraints require.

Finally, notice that when *k* is very high, there is an huge gap between welfare in the non co-operative and in the co-operative equilibria. The first can even be negative. This is due the mentioned fact that in this case each country is helpless against the other's country emissions and this affects more the high damage cost one than the low cost one. The first country's expected welfare can then turn out to be negative and the second's one, although always positive, may be not high enough to make the total expected welfare positive. Notice that this does not necessarily imply that the best option for the high cost country is to shut down its own firms' plants, because this choice will leave the entire world market to the other country, which will then produce more and pollute even more than before the high damage cost country. The only way out for the latter would then be to insist on a co-operative agreement, that, in both information settings, will make both countries better off.

[41] Strictly speaking, the full information co-operative equilibrium is still not a first best optimum because of the duopolistic market structure in the second stage game.

Figure 5. Emission Standards.

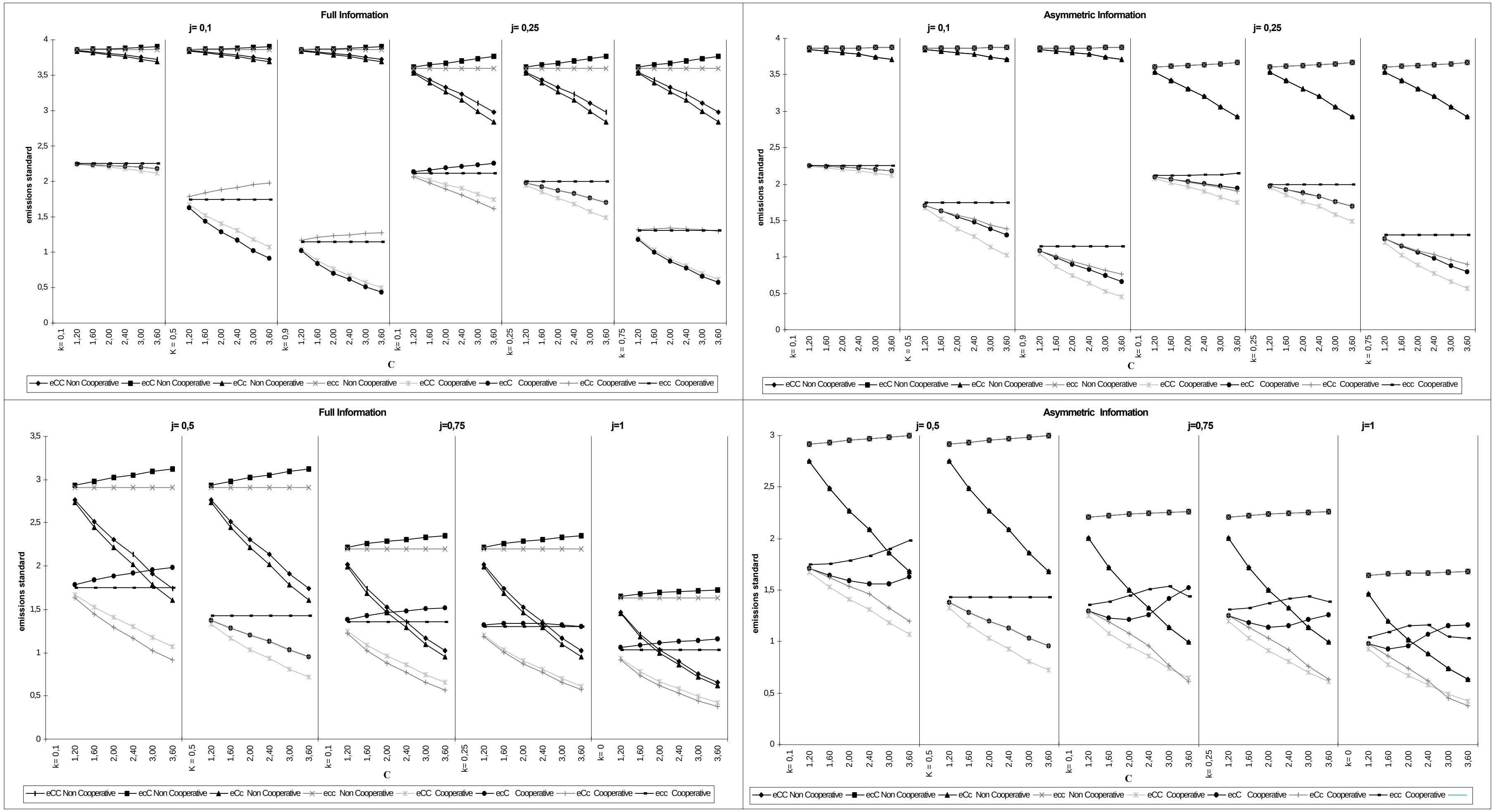
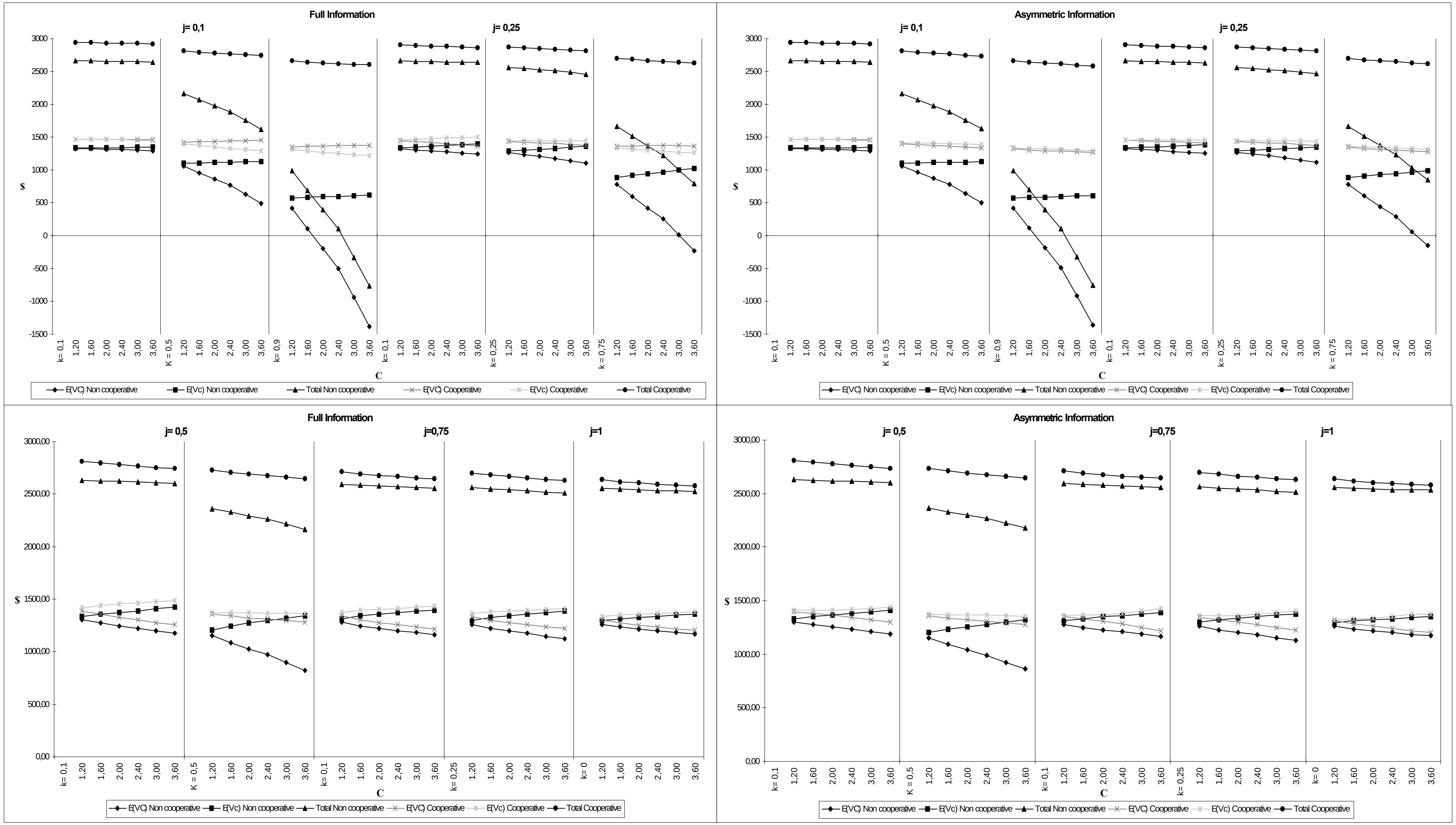


Figure 6. Welfare Levels.



3. Conclusions.

In this paper we have extended a model of A. Ulph (1997) in order to analyse some features of the Environmental regulation of the electricity sector in a European context.

Ulph's model considers two countries, one firm per country, one national regulator in each country and one supra-national regulator. In a full information setting, the national regulators select the level of emission standards taking into account its implication for firms' profits and environmental damages. If this is done in a non co-operative way, it results in inefficient levels of the standards, a situation often referred to as "eco-dumping". Thus, a role can arise for a supra-national regulator (the "European Commission") which tries to co-ordinate the national environmental policies. Two situations are considered. In the first one, the Commission has full information, but is unable to enforce the co-operative equilibrium; it may then resort to harmonisation or emission ceiling in order to improve on the non co-operative solution. In the second one asymmetric information about the countries damages is assumed, and the Commission takes charge directly of national environmental policies, and asks national governments to report on their country's damages. It will then design a mechanism aimed at improving on the non co-operative solution while eliciting truthful revelation on the part of the national regulators.

Ulph's first conclusion was that, in a full information setting "harmonisation of environmental policies will not achieve a Pareto improvement over the non co-operative outcome if countries have more than modest differences in their environmental damage costs." We found that this result, when we allow for transboundary pollution, turns out to be more an exception than the rule, and that, when the main source of external cost for a country are foreign emissions, damage costs can be very different between the two countries and harmonisation still represents an improvement over the non co-operative equilibrium.

Finally, as to asymmetric information results, Ulph's finding was that "when the Commission lacks information about the damage costs of individual countries, (...) setting less differentiated policies across countries" may be required. This result is also broadly confirmed by our analysis, although new elements demand consideration in the case of transboundary pollution.

In order to extend Ulph's framework, we have first briefly discussed the inclusion of consumer surplus. Our opinion is that it will just replicate the incentives exerted on the national governments by firm profits. In practice, consumer's surplus consideration will lead national government to implement even less strict environmental policies, and has limited influence on the results.

In the rest of the paper, we have considered transboundary pollution. This brought along a number of important changes. To sum them up, it affects the governments' incentives to misreport, making them stronger and changing the kind of report the Commission should be wary of, it calls for a much less differentiated treatment of the countries, and makes co-operating or delegating the regulatory power to the Commission a much more attractive option than the non co-operative equilibria.

Ulph also found that financial transfers are hardly ever useful. In fact they are adopted only when the social costs of public funds are zero or in the rare event that their social cost equals the shadow price of truthful information. This result is also confirmed by our analysis.

This study can be extended in many ways. A first obvious possibility is to consider environmental taxes instead of environmental standards. In Europe, polluting emissions are prevalently regulated by means of standards, but there are already a few examples of the use of taxes for this purpose (e.g. France for SO_x and NO_x , Denmark and Sweden for CO_2 and SO_2). In the case of taxes our analysis with transboundary pollution becomes more complicated because, even assuming additive damage functions does not help to get rid of the interaction effects, since each country emissions depend directly on the other country's emissions trough the equilibrium tax rate. This may result in unstable reaction curves in case of highly transboundary pollution.

Exploring other forms of competition may also be interesting, especially in view of the mixture of Bertrand and Cournot Competition which is likely to take place in an open European electricity market, according to Smeers (1997). For instance one could try to split the last stage of the game in two and consider an investment stage in which firms choose their capacities, followed by a Bertrand competition stage in which second lowest marginal cost pricing takes place[42]. Introducing an investment stage will allow the consideration of environmental adders[43] as an additional instrument. As long as these extensions do not change the slope of the countries reaction functions, no big consequences can be expected, although under alternative forms of imperfect competition the role of the surplus of the European electricity consumers may become more relevant.

In Ulph's framework, countries differ only in their environmental damages. It would be also interesting to consider other sources of asymmetry. For instance, in view of the lack of uniformity in environmental policies among the E.U. member states, a natural extension

[42] See Kreps and Scheinkman (1983), and Wei and Smeers (1996).

[43] Environmental adders have been used in the planning decisions of some American Public Utility Commissions. A value for external cost is added to marginal generation cost and new investments in generation capacities are optimally chosen taking this social cost into account. See Busshnell and Oren (1994) and Martin (1995).

would be allowing the two governments to use different environmental instruments. Another source of heterogeneity worth exploring are differences in generation costs. This would allow us to take into account the fact that European countries differ a lot in their generation technology choices, sometimes not for economic reasons, but because of political decisions or natural characteristics of their territory. Some countries (e.g. Italy) have banned nuclear generation, other can count on a larger share of renewable sources (e.g. Scandinavian countries). Since different fuels have different environmental damages, this should be reflected also in the countries damage functions. However given the number and the complexity of decision involved this issue can be probably better analysed within a computable partial equilibrium model.

Appendix A.

Proof of Proposition 1: In case a) the result can be shown as follows: recall that, when *j is sufficiently large compared to k*, we have $\frac{\partial e^*}{\partial d} < 0$ and $\frac{\partial e^*}{\partial \delta} > 0$; using the first inequality, we can then establish that $e^*_{CC} < e^*_{cC}$ and $e^*_{Cc} < e^*_{cc}$; using the second inequality we get $e^*_{cc} < e^*_{cC}$ and $e^*_{Cc} < e^*_{CC}$. It follows then that

$$e^*(C,c,j,k) < e^*(C,C,j,k) \gtreqless e^*(c,c,j,k) < e^*(c,C,j,k). \qquad \text{(A1)}$$

In order to establish the ranking between e^*_{cc} and $e^*_{CC,}$ consider again the first order conditions. When both countries have low environmental damage parameters, these conditions imply that for both countries, it must be

$$A'(e^*_{cc}) = cjD'(je^*_{cc}) + ckD'(ke^*_{cc}) - R_2(X_e + Y_e), \qquad \text{(A2)}$$

If the damage parameters of both countries increase to C, this rule calls for an increase in marginal abatement, and hence stricter emission limits. It must then be $e^*_{CC} < e^*_{cc}$.

In case b) the result can be shown reasoning along the same lines, using the same argument on the first order condition and the fact that, when *j is sufficiently small compared to k*, $\frac{\partial e^*}{\partial d} > 0$ and $\frac{\partial e^*}{\partial \delta} < 0$.

In case c), the result can be shown as follows. Let $j = k = l$. When $d = c$ and $\delta = C$, the first order conditions imply :

$$A'(e^*_{cC}) = clD'(le^*_{cC}) + ClD'(le^*_{cC}) - R_2(X_e + Y_e) \qquad \text{(A3)}$$

$$A'(e^*_{Cc}) = ClD'(le^*_{Cc}) + clD'(le^*_{Cc}) - R_2(X_e + Y_e). \qquad \text{(A4)}$$

on the other hand, when $d = C$ and $\delta = c$, the first order conditions imply :

$$A'(e^*_{Cc}) = ClD'(le^*_{Cc}) + clD'(le^*_{Cc}) - R_2(X_e + Y_e) \qquad \text{(A5)}$$

$$A'(e^*_{cC}) = clD'(le^*_{cC}) + ClD'(le^*_{cC}) - R_2(X_e + Y_e). \qquad \text{(A6)}$$

Notice that these are the same conditions as (A3) and (A4). This implies that in this case, $e^*_{Cc} = e^*_{cC}$.

When $d = \delta = c$, these conditions imply, for both countries:

$$A'\left(e^*_{cc}\right) = clD'\left(le^*_{cc}\right) + clD'\left(le^*_{cc}\right) - R_2\left(X_e + Y_e\right). \qquad \text{(A7)}$$

On the other hand, when $d = \delta = C$, we have :

$$A'\left(e^*_{CC}\right) = ClD'\left(le^*_{CC}\right) + ClD'\left(le^*_{CC}\right) - R_2\left(X_e + Y_e\right). \qquad \text{(A8)}$$

Reasoning as for case a), it must then be $e^*_{CC} < e^*_{cc}$. It is then trivial to show, by contradiction, that it can only be $e^*_{CC} < e^*_{Cc} = e^*_{cC} < e^*_{cc}$, for any sign of $\frac{\partial e^*}{\partial d}$ and $\frac{\partial e^*}{\partial \delta}$.

In case d) the ranking is incomplete because the negative sign of both $\frac{\partial e^*}{\partial d}$ and $\frac{\partial e^*}{\partial \delta}$ (holding when j is not too different from k) requires that $e^*_{CC} < e^*_{cC}$, $e^*_{cC} < e^*_{cc}$, $e^*_{Cc} < e^*_{cc}$, but does not allow us to rank e^*_{cC} versus e^*_{cC}. The ranking of e^*_{CC} versus e^*_{cc}, follows again from the first order conditions as in the previous case.

Appendix B.

Proof of Proposition 2: From condition (13a) follows that it is either

$V_1(\ddot{e}_c, \ddot{e}_C, c, j) < 0 < V_1(\ddot{e}_c, \ddot{e}_c, c, j)$ or (B1)

$V_1(\ddot{e}_c, \ddot{e}_c, c, j) < 0 < V_1(\ddot{e}_c, \ddot{e}_C, c, j)$[44]. (B2)

Now, both conditions (13a) and (13b) also imply that $\frac{\partial \ddot{e}}{\partial d} = -(1-p+p)V_{13}/(1-p+p)V_{11} < 0$, which in turn implies $\ddot{e}_c > \ddot{e}_C$. Since $V_{12} < 0$, it follows that the second inequality above is true and the first is false.

Since in the non co-operative equilibrium under perfect information the equilibrium level standard $\hat{e}_{cc}$ satisfies the first order condition $V_1(\hat{e}_{cc}, \hat{e}_{cc}, c, j) = 0$ when both countries have low damage costs, it follows that $V_1(\ddot{e}_c, \ddot{e}_c, c, j) < V_1(\hat{e}_{cc}, \hat{e}_{cc}, c, j) = 0$. This in turn implies that $\ddot{e}_c > \hat{e}_{cc}$.

Analogously, from condition (13b) follows that

$V_1(\ddot{e}_C, \ddot{e}_c, C, j) < 0 < V_1(\ddot{e}_C, \ddot{e}_C, C, j)$. (B3)

This implies $0 = V_1(\hat{e}_{CC}, \hat{e}_{CC}, C, j) < V_1(\ddot{e}_C, \ddot{e}_C, C, j)$, from which follows $\hat{e}_{CC} > \ddot{e}_C$.

Since we have already shown that $\hat{e}_{Cc} < \hat{e}_{CC} < \hat{e}_{cc} < \hat{e}_{cC}$, and we know that VC and Vc are linear combinations of convex functions, it follows that

$$\hat{e}_{cc} = \arg\max_e V(e, f, c, c, j) < \ddot{e}_c < \arg\max_e V(e, f, c, C, j) = \hat{e}_{cC} \text{ and} \qquad \text{(B4)}$$

$$\hat{e}_{Cc} = \arg\max_e V(e, f, C, c, j) < \ddot{e}_C < \arg\max_e V(e, f, C, C, j) = \hat{e}_{CC}. \qquad \text{(B5)}$$

This concludes the proof.

Appendix C.

Proof of Proposition 3: In order to determine which constraint is binding and under which conditions, consider the difference

$$
\begin{aligned}
&f\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, c\right) - f\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, C\right) = \\
&(C-c)\Big\{p\Big[j\big(D(je_{cc}) - D(je_{Cc})\big) + k\big(D(ke_{cc}) - D(ke_{cC})\big)\Big]\Big\} \qquad \text{(C1)} \\
&+(1-p)\Big[j\big(D(je_{cC}) - D(je_{CC})\big) + k\big(D(ke_{Cc}) - D(ke_{CC})\big)\Big]
\end{aligned}
$$

In the proximity of the full information co-operative equilibrium, this difference will be *positive* when $j \geq k$. In fact when $j = k$, the ranking is $e^*_{CC} < e^*_{Cc} = e^*_{cC} < e^*_{cc}$. This implies that in this case, the difference above is positive. On the other hand, when j is larger enough than k, the ranking is $e^*_{Cc} < e^*_{CC} < e^*_{cc} < e^*_{cC}$, which implies that the terms in (C1) multiplied by j will be positive and those multiplied by k will be negative. It follows that for j large enough compared to k the difference above is surely positive. However we have just seen that (C1) is positive when $j = k$ and hence it must be also positive for any $j \geq k$. This is also confirmed by the fact that, when j and k do not differ too much, the (incomplete) ranking is $e^*_{CC} < e^*_{Cc} \gtrless e^*_{cC} < e^*_{cc}$, which again implies that the difference in (C1) is positive[45].

Consider also a first order expansion of $f(e_{CC}\ e_{Cc}, e_{cC}, e_{cc}, d)$ around the full information equilibrium, for $d = c, C$:

$$
f\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, d\right) \cong 2p\Big[\left(e^*_{cc} - e^*_{Cc}\right)V_1 + \left(e^*_{cc} - e^*_{cC}\right)V_2\Big] + 2(1-p)\Big[\left(e^*_{cC} - e^*_{CC}\right)V_1 + \left(e^*_{Cc} - e^*_{CC}\right)V_2\Big] \qquad \text{(C2)}
$$

$f\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, d\right)$ will be *positive* when $j > k$ and *negative* when $j < k$, in the proximity of the full information co-operative equilibrium. This follows from the fact that, in the proximity of the full information co-operative equilibrium, $V_1 + V_2 = 0$ and hence $V_1 > 0$ and $V_2 < 0$, and from the aforementioned different rankings of environmental standard according to j and k in the full information co-operative equilibrium.

When $j = k$, $e^*_{Cc} = e^*_{cC}$. This implies that in this case, we have,

$$
f\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, C\right) \cong 2\left[V_1 + V_2\right]\left[p\left(e^*_{cc} - e^*_{cC}\right) + (1-p)\left(e^*_{cC} - e^*_{CC}\right)\right] = 0 \qquad \text{(C3)}
$$

because in the proximity of the full information co-operative equilibrium, $V_1 + V_2 = 0$. Thus, when $j = k$, the expected payoff from lying is zero, and we have

$$
f\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, c\right) > f\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, C\right) = 0 \qquad \text{(C4)}
$$

[46].

---

[44] In fact, if it had been $V_1(\ddot{e}_c, \ddot{e}_c, c, j) = 0$ the first order condition (13) could have been satisfied only if $p = 1$ or also $V_1(\ddot{e}_c, \ddot{e}_C, c, j) = 0$; that is, only if $c = C$, or if uncertainty had not been an issue in the first place. Thus, in non trivial cases, strict inequalities must apply.

[45] Thus, (C1) is positive also when j is smaller than k, but not too much. For larger differences between j and k, when $j < k$, the sign of (C1) is undetermined. Fortunately, however, in that case determining that sign it is not relevant for the purpose of finding the binding constraint.

[46] Since the approximation in (C3) holds also for $f\left(e^*_{cc}, e^*_{Cc}, ee^*_{cC}, e^*_{CC}, c\right)$, the difference in (C1) must be just an $\varepsilon > 0$ with ε arbitrarily small. This makes sense, because, as we have shown, that difference is positive and larger the bigger j is than k.

Hence, around the full information co-operative equilibrium[47], when there are no financial transfers and $j = k$, both the incentive compatibility constraints will be satisfied, although the one for a country with high environmental damages as an equality when $M = 0$ and it will be strictly not binding only when $M > 0$.

We can then conclude that

a) when $j > k$, $\mathrm{f}\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, c\right) > \mathrm{f}\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, C\right) > 0$;

b) when *j is smaller enough than k*, $\mathrm{f}\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, c\right) < 0$ and $\mathrm{f}\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, C\right) < 0$;

c) when *j is smaller than k*, but not too much, $\mathrm{f}\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, c\right) > 0 > \mathrm{f}\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, C\right)$;

d) when $j = k$, $\mathrm{f}\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, c\right) > \mathrm{f}\left(e^*_{cc}, e^*_{Cc}, e^*_{cC}, e^*_{CC}, C\right) = 0$.

Results a) to d) are equivalent to *Proposition 3*.

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[47] We relate the governments’ incentives for lying to the full information cooperative equilibrium because it makes sense for a government to lie only if he (naively) expects that is report will be believed, and that the Commission will behave as under full information. The Commission, however, is well aware of the governments’ incentives to lie.

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