Unilateral actions
the case of international environmental problems

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Abstract

When abatement costs are uncertain, but correlated, and a country becomes privately informed that costs are low, then unilateral actions serve as a signalling devise to reveal low costs and unilateral actions have the potential to trigger positive responses abroad. However, the country engaging in unilateral actions is the one with the highest expectation about the other countries' reactions, and it might suffer from an effect like the winners curse.

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1. Introduction

The lack of supranational authority implies that international policy measures must rely solely on voluntarily contributions. Barrett (1990 and 1994) seriously questions the effectiveness of international environmental agreements, as exemplified by the troublesome process of regime building for the climate change issue. The reason is that the creation of the right set of incentives for voluntary reductions of emissions in excess of purely non-coordinated reduction levels is not easy. Therefore, a very concerned country might initiate unilateral actions if such actions act as 'setting a good example'. Unilateral actions appear in many areas of the international society such as unilateral reductions in armaments, unilateral aid to developing countries, unilateral reductions in trade sanctions or increases of trade concessions, and in the field of transboundary pollution problems, unilateral cut backs in emissions. Unilateral actions to alleviate IEP have been analysed in e.g. Hoel (1991) and Barrett (1990). A rather pessimistic result emerges in both and can be summarized by saying that leadership of this kind is seldom rewarded.

The main purpose of this paper is to re-examine the prospect of unilateral actions providing a non-cooperative alternative to the cooperative actions of multinational negotiations. Although it cannot be expected that such actions will, at any point, bring about a fully cooperative solution, they nevertheless might make a difference in overcoming the first, and potentially most troublesome phase, in the process of building up an effective reduction regime when incentives do not support cooperation.

In the model of Hoel (1991), two countries play a non co-operative game each maximizing the net-benefit from reducing environmentally harmful emissions. One country, however, also cares about the emission reductions in the other country. This is modelled by introducing a function containing non-economic variables. Such unilateral actions might be justified as being a contribution in the right direction, and also, by setting a good example of this type, one might affect the behaviour of other countries, and/or improve the chances of reaching international agreements for co-ordinated reductions of harmful emissions. The main findings in Hoel's paper are that unilateral actions will at its best reduce the overall emission level (but by less than the unilateral reduction itself), but at worse, they might actually increase total emissions. Hoel (1991, p.69) concludes that: "it might not be particularly sensible for an environmental group in a country to try to force its government to unilaterally reduce the countries emissions".

Hoel (1991) mentions 'setting a good example' as being the reason for unilateral actions, without explicitly modelling how such a good example could be accomplished. In this paper unilateral actions are re-formulated, not as setting a good example, but rather as transmitting relevant information. In order for unilateral actions to work they must somehow transmit information that directly alters the position of the reaction functions of the other countries in a preferred direction from the initiators' point of view.[1]

This is accomplished by invoking three assumptions. First, the costs are fully correlated between countries. The second is that a country can be fully (but privately) informed about the relevant cost parameter, and this incurs a fixed cost. Finally, it is assumed that no verification technologies exist, which implies that transmission of information is only possible by making a reduction effort. Given these assumptions, unilateral actions are indeed profitable. The prospect or likelihood of unilateral actions depends on the finer details of the information-structure, and if the above assumptions are satisfied, unilateral actions are shown to always be profitable. Two common-sense results are derived: the first is that the higher the correlation, the more likely that unilateral actions are prof-

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1 Our signalling approach resembles the idea of 'leading by example', analysed in Hermalin (1998). Here the leader is defined on the basis of being better informed, and has to undertake some costly effort to convince the others that effort is worthwhile undertaking. The difference between the two approaches is that in our model, the countries are initially uninformed, but can choose to become informed, which is costly. Hence, the choice of getting informed is determined endogenously in the model and in this respect resembles the approach of Kessler (1998). She discusses the idea of undertaking a costly information gathering activity in order to become (privately) informed.

itable, and second, if a country can only get imperfect information, then unilateral actions are less likely.

To gain further insight into the cause and prospect of unilateral action not found in Hoel (1991), two additional changes are made. First, the countries differ with respect to the expected response of the other countries if valuable information is revealed to these countries. The second change is to introduce a simple model where the decision about the level of environmental regulation in a country is determined by the lobbying activities of two pressure groups in that country: An industrial group lobbying for no reductions and an environmental group lobbying for a high level of reduction. The more pressure a group exerts, the more it influences the policy outcome. The observation that the political process in a country is polymorphic is also analysed in e.g. Dijkstra (1999), on basis of an influential function.

Unilateral actions are most likely when costs are positively correlated, when a country can be fully informed at low costs and a country can receive a perfect signal. Unilateral actions are most likely when countries initially are reluctantly to engage in any significant reduction effort, which could be caused by pressure from lobby groups. Moreover, the model yields a broader framework for understanding the reasons why a country moves first, the initial positions of the countries and how transmission of information interferes with policy choices in other countries. Finally, an interesting result emerges regarding which country initiates unilateral actions: The curse of the country that initiates the unilateral action is that, since it is the country with the highest estimate of the response of the other countries in case reduction costs are revealed as low, this country is likely to over-estimate the actual response of the other countries. This might explain why unilateral actions are initiated, but as Barrett (1990) claims, initiatives of this kind are seldom rewarded.

The paper is organized as follows: In section 2, the basic model is presented, and in section 3, private information about costs is introduced. Section 4 shows how Hoel's (1991) results also carries over to the situation with private information about costs. The insight gained in the first part of the paper is used in section 5 to model a situation, where unilateral actions are possible, which is formally shown in section 6. In section 7, we relax the assumptions and this shows the robustness of our results. Finally, an alternative specification of the way environmental policy is determined is given in section 8, while section 9 concludes the paper.

2. Model

First, a model of an international environmental problem that resembles the original specification of Hoel (1991) will be presented. This will enable us to use Hoel's model as a benchmark and his results as a point of departure for further analysis. The set of countries is $I = \{1,2,...,N\}$. Each country emits e_i, the polluting substance, which cause environmental degradation both domestically and abroad. For simplicity, assume auniformly mixed pollutant giving rise to a global emission problem. Hence, each country is affected by the total emission level $e = \sum_i e_i$. Let the emission level in the case of no environmental concern be e_i^o, and assume that $e_i \in [0, e_i^o]$.[2] Compared to e_i^o, a country might undertake certain reduction effort. Let $q_i = e_i^o - e_i$ be the actual reduction level of country *i*, hence the level of reductions is measured by how much emissions are reduced compared to e_i^o. We have that $q_i \in Q_i = [0, e_i^o]$. Due to the global pollutant assumption, it is the total reduction level, $q = \sum_i q_i$, that is relevant for a country's reduced level of environmental degradation.

2 Although the possibility of emissions above e_i^o cannot simply be excluded, we dismiss this possibility here. See Brandt (2002) for a model where, for strategic reasons, emissions are increased above the short run optimal levels (and possibly above e_i^o).

$B_i(q)$ measures the benefits to country *i* from total reduction, *q*. On the other hand, costs of controlling emissions only depend on own reductions, q_i, and are measured by $C_i(q_i)$. We make the standard assumptions on the functions that $B_i^{'}(q) > 0$ and $B_i^{''}(q) < 0$ while $C_i^{'}(q_i) > 0$ and $\mathrm{C}_i^{''}(q_i) > 0$.[3] Hence, the net-benefit to country *i* from own and total reduction efforts amounts to:

$$NB_i = B_i(q) - C_i(q_i), \ \mathrm{i} = 1{,}2 \tag{1}$$

Given the assumptions, the net benefit functions are strictly concave in q_i. If each country behaves non co-operatively, it maximises its own net-benefit function with respect to its own reductions, q_i, considering only damage in its own country but not the damage it causes in other countries, or alternatively, not considering the public good character of own reduction. The first order condition for a country to maximize its net benefit in a non-cooperative setting is obtained by differentiating (1) with respect to own reductions, taking the other countries' reductions, q_{-i} as given:

$$NB_i^{'} = B_i^{'}(q) - C_i^{'}(q_i) = 0$$

Define the best reply function, or the reaction function of country *i*, as the function that relates the optimal choice of country *i* to the choice of reduction of the other countries, $q_i = q_i(q_{-i})$. The slope of this function is determined as $\frac{\partial q_i(q_{-i})}{\partial q_{-i}} = \frac{B_i^{''}}{C_i^{''} - B_i^{''}}$.[4] Since $B_i^{''}(q) < 0 \quad \mathrm{C}_i^{''}(q_i) > 0$, we have that $-1 < \frac{\partial q_i(q_{-i})}{\partial q_{-i}} < 0$. Moreover, given the assumptions on the benefit and cost functions, there exists a unique (and interior) Nash-equilibrium given by $q^{nc} = \{q_1^{nc}, q_2^{nc},,, q_n^{nc}\}$ at the

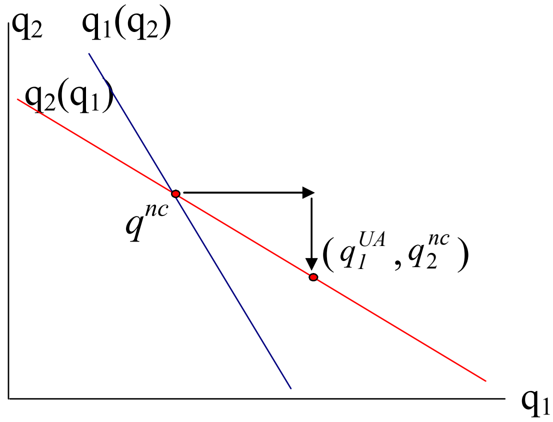
3 For a more detailed discussion of these assumptions, see e.g. Finus (2001).

4 Conditions that guarantee a unique (and interior) Nash equilibrium are given in Finus (2001, chapter 9).

intersection of the reaction curves.[5] Assume that in the case of no coordination, these levels will result.[6]

The immediate question arises of how to define a unilateral action, since unilateral movement away from a Nash-equilibrium is not a self-enforcing move? In Hoel (1991), this is accomplished by assuming that one country acts as if it is not maximizing (1), but instead $NB_i = B_i(q) - C(q_i) + h \cdot \sum q_i$, where h>0 indicates that the country also benefits from reduction in ways not covered by the cost and benefit relations defined in (1).[7] Hoel (1991) stresses that h are not a choice variable.

Figure 1. The effect of a unilateral increase in reductions by country 1



Given the definition given above, what happens in Hoel's case is easily determined. Since reductions are strategic substitutes, i.e. $\frac{\partial q_i(q_j)}{\partial q_j} < 0$, any unilateral increase in reductions by one country will be responded to by a decrease in reductions by all other countries. This is illustrated in a two-country version, in

5 We occasionally use vector notation $B_i(q_i, q_{-i}^{nc})$, which, due to the assumption of a uniformly mixed pollutant, is equal to $B_i(q_i + \sum_{j \neq i} q_j^{nc})$.

6 This is a common observation; see e.g. Hoel (1997).

7 See Hoel (1991) for a precise definition of h. In this way Hoel defines that any reduction above the Nash equilibrium is a unilateral action, and at the same time it is in a sense a new stable situation since there will be no further adjustments.

figure 1. Although total reductions might be increased by a unilateral move, it does not seem to be a good idea for country *i* to engage in unilateral actions, if its aim of setting a good example will be strategically exploited by other countries. No rational country will ever find it worthwhile to undertake unilateral actions under this model.

One shortcoming with Hoel's approach is that *h* remains unexplained. It does not seem to be rational for a country to engage in unilateral actions when it knows the above relationship. This is why *h* cannot be a choice variable in Hoel's model. The interesting question remains: Can unilateral actions be rational (i.e. result from optimising behaviour) if Hoel's (1991) reaction function approach is used without conditioning unilateral actions on the presence of non-choice variables?

We turn now to an examination of the way the costs influence the Nash-equilibrium. Let θ_i be a shifting parameter in the cost function of country *i*, such that:

$$C_i(q_i, \theta_i^1) > C_i(q_i, \theta_i^2) \text{ for } \theta_i^1 > \theta_i^2 \text{ for all } q_i \in Q_i \text{ and } \frac{\partial C_1}{\partial \theta_1} > 0 \tag{2}$$

In appendix 1, it is shown that

$$\frac{\partial q_1^{nc}}{\partial \theta_1} < 0 \text{ and } \frac{\partial q_2^{nc}}{\partial \theta_1} > 0, \forall \mathrm{i}, \mathrm{j} \in \mathrm{I} \tag{3}$$

The intuition behind (3) is that increased costs in country 1 lead to less reductions by country 1, which increases the marginal benefit to country 2 (as long as country 2 does not change its emission). Hence, country 2 will respond by increasing its reduction efforts.

3. Cost uncertainty

Next, private information about reduction costs is introduced. The main purpose of this section is to show how to determine an expected (or Bayesian) Nash equilibrium and how revelation of information can result in changes in reductions by the other countries. This model serves as a (benchmark) framework for the following, focusing exclusively on the effect stemming from information transmission.

Assume two possible cost types, low cost countries, denoted L and high cost countries, denoted H, i.e., $\theta_i \in \{L, H\}$. Let $\rho_j = prob(\theta_j = L)$ be the (common) prior probability that the cost parameter of country j is low, with $\theta = (\theta_1, \theta_2, ..., \theta_n)$. Let $\rho = (\rho_1, \rho_2, ..., \rho_n)$ be the vector of common prior beliefs about the types of the n countries.

The reaction function of country i, in the most general form, is given by $q_i = q_i(\theta_i, q_{-i}(\rho), \rho)$, which says that the best reply function by country i is dependent on own type, θ_i, expected choice of reductions of the other countries, $q_{-i}(\rho)$, and the common prior belief vector, ρ. In a two country version, $q_1 = q_1(\theta_1, q_2(\theta), \theta)$ denotes the reaction function for country 1 under full information, while $q_1 = q_1(q_2(\rho), \rho)$ is the situation with complete uncertainty. The non-cooperative (Nash) equilibrium is given by $q_i^{nc} = q_i^{nc}(\rho)$ under complete uncertainty, and $q_i^{nc} = q_i^{nc}(\theta)$ under full information and two countries. Most importantly, it follows from (3),[8] that

$$\frac{\partial q_j^{nc}}{\partial \rho_i} < 0 \tag{4}$$

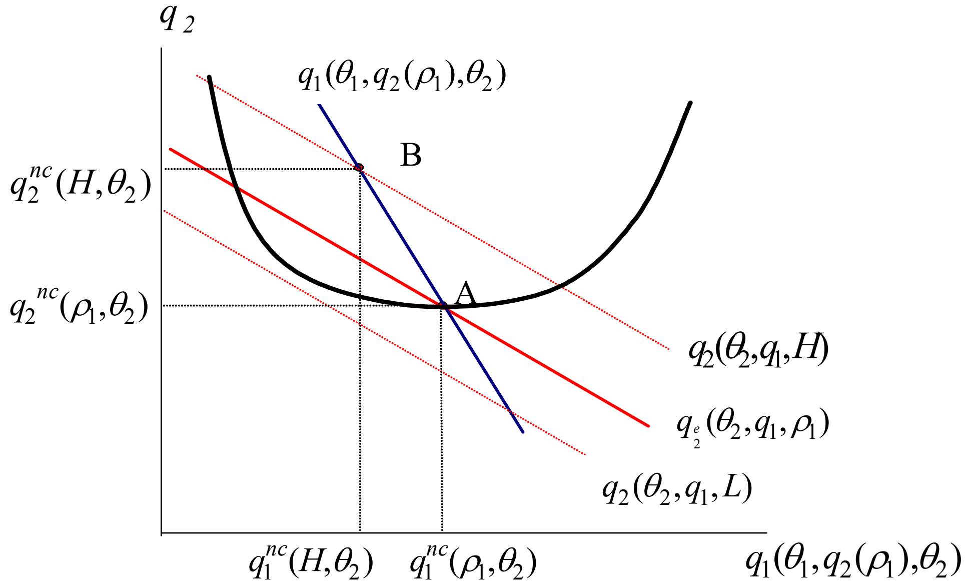
8 To see this, remember that $\frac{\partial q_i}{\partial \theta_j} > 0$, which says that the higher another countries' costs, the higher the own reduction. Since ρ is the probability for low costs, the more likely that the other country has low costs, the lower will be the own reduction.

This derivative forms the basic incentives in the first part of this paper.

To illustrate how revelation of information influences the choices in the non-cooperative equilibrium, assume the following one-period structure: the cost to country 2, θ_i, is common knowledge, while the cost of country 1 is private information to this country, whereas country 2 hold a prior belief of ρ_1 that its cost is low.[9] This case is illustrated in figure 2. The relevant reaction function for country 1 is $q_1 = q_1(\theta_1, q_2(\rho_1), \theta_2)$. Since it knows both countries' costs, its reaction function does not change when beliefs change. The reaction function for country 2 is: $q_2 = q_2(\theta_2, q_1, \rho_1)$. Here, the position of the reaction functions shift with changes in ρ_1, i.e., if costs are revealed as high, then the reaction function shifts upwards, as illustrated in figure 2. Now, how can country 1 increase the reductions of country 2? If it is revealed that the costs of country 1 are high, then due to (3), country 2 increases its reductions from $q_2^{nc}(\rho_1, \theta_2)$ to $q_2^{nc}(H, \theta_2)$, while at the same time the reduction of country 1 decreases from $q_1^{nc}(\rho_1, \theta_2)$ to $q_1^{nc}(H, \theta_2)$. In figure 2, the indifference curve going through point A shows that this is a preferred point for country 1. If country 1 can report verifiable information about θ_i costlessly, (or at sufficiently low cost) to country 2, or when the costs of being informed are small, then it is optimal for country *i* to reveal its costs.

9 See Tirole (1988, ch. 8) for a detailed examination on this issue.

Figure 2. Changes in the equilibrium when costs are revealed



Note, however, that if it costs turn out to be low, then county 1 has an incentive to hide this knowledge. We will come back to these incentives in section 5. But this is not, however, the end of the story. The low cost country has the same incentives as the high cost country to try to persuade the uninformed country that costs are high. In order for the high cost type to be perceived as having truly high costs, it must engage in an action that perfectly distinguishes it from the shadow of the low cost country. The appropriate way to analyse this is by use of a signalling game model.

4. Signalling game 1: Incentives to signal that costs are high

In the signalling game 1, we focus on the revelation of one country's costs. The other countries could have private information about their costs, be uncertain about their costs or be fully informed. Country i has private information about costs, while the others hold a prior belief about its costs. We assume that although it is common knowledge that this country is completely informed about costs, there exists no verification technology. The reason for this is that no matter what the true state of costs is, the informed country always has a strong incentive to announce that costs are high. The only way a country can convince the relevant parties that it has high costs, is by engaging in a unilateral deviation from the non-cooperative optimum by such an amount that only a country with high costs will find it worthwhile undertaking.

Now an abstract signalling game model is setup. In period 1, the informed country can choose to signal its costs by deviating from non-cooperative reduction path. The other countries choose their output on the basis of their best reply function (which is based on their prior cost estimates). Next they evaluate the chosen outcomes, and update their beliefs by use of Bayes rule. On the basis of these new beliefs, they play their best reply in the second period.

The following notation will be used:

Choice in period 1:	q_i^1	q_{-i}^1
Updating of beliefs:	$\rho_i(q^1)$	$\rho_{-i}(q^1)$
Choice in period 2:	$q_i^2(\rho_i(q^1))$	$q_{-i}^2(\rho_{-i}(q^1))$

Superscripts denote periods and $q^1 = (q_i, q_{-i}^1)$ is the total vector of outputs in period 1. Note that second period choices are fully determined by first-period actions and prior beliefs. Initially, nature draws a type θ from the set {L, H}, according to a probability distribution (ρ, 1-ρ) where ρ=*prob* (θ=*L*). $NB_i(\theta, q_i, \rho) = NB_i(q_i^1, q_{-i}^1, \rho_i, \theta_i) + NB_i(q_i^2(\rho_i(q^1)), q_{-i}^2(\rho_{-i}(q^1)), \theta_i)$ is the two-period net benefit for country *i* from playing q_i, and the optimal response from country j, given country i's type in both periods.[10] Moreover, let *q*(*L,1*) and *q*(*H,0*) be the full information maximizer of NB_i for the low costs and the high cost types, respectively. Note that *q*(*H,0*) < *q*(*L,1*), see figure 3 for an example.

10 Assume no discounting. In general including discounting makes unilateral actions less likely, since it reduces the second period gains from a unilateral action.

Sequential equilibrium

We restrict attention to pure strategy equilibria. Consequently, there remains two different kinds of equilibria; separating equilibria, where each type send different signals, and pooling equilibria where the two types send the same signal. Since the analysis focuses on the prospects of unilateral actions, focus is exclusively on sequential separating equilibrium, or more precisely, interest is on finding condition for a separating equilibrium to exist. In a separating equilibrium, the receiver can perfectly infer the type of the sender. Formally, a collection of reduction levels and beliefs $\{\hat{q}_H, \hat{q}_L, \hat{\rho}(q)\}$ forms a sequential equilibrium if the following conditions are satisfied:

i) Optimality for the country with costs θ:

$$\hat{q}_\theta \in arg\,max\, NB_i(\theta, q_i, \hat{\rho}(q_i))$$

ii) Beliefs are Bayes-consistent:

a) *If* $\hat{q}_H \neq \hat{q}_L$ *then* $\hat{\rho}(\hat{q}_H) = 0$ *and* $\hat{\rho}(\hat{q}_L) = 1$

b) *If* $\hat{q}_H = \hat{q}_L$ *then* $\hat{\rho}(\hat{q}_H) = \hat{\rho}(\hat{q}_L) = \rho^o$

c) *If* $q_\theta \neq \{\hat{q}_H, \hat{q}_L\}$ *then* any $\hat{\rho}(q_\theta)$ is admissible

After observing q_i, the receiver must form a belief about which types could have sent q_i. These posterior beliefs are denoted $\rho(\theta/q_i)$ with $\rho(L/q_i)+\rho(H/q_i)=1$. The first requirement of strategies that form a sequential equilibrium is sequential rationality, which amounts to saying that for each q_i, q_j must maximise expected payoffs, given the beliefs. Regarding the optimality of beliefs, if $\hat{q}_H \neq \hat{q}_L$ and the receiver observes, e.g., $\hat{q}_H$, then it must be that costs are high, and the only consistent belief is $\hat{\rho}(\hat{q}_H) = 0$ and given this belief, it is optimal for the high cost type to play $\hat{q}_H$. In this particular signalling game the requirement of consistency of beliefs does not place any restrictions on beliefs following out-of-equilibrium signals, i.e., any beliefs are admissible if an out-of-equilibrium outcome is observed.

Separating equilibrium

In a separating equilibrium, the high cost type succeeds in separating from the low cost type, and is, therefore, always recognized as a high cost type, while the low cost type is revealed as a low cost type. In order to fully describe the set of possible separating equilibrium outcomes, it is assumed that out-of equilibrium signals are followed by the most unfavorable beliefs seen from the informed country's point of view, i.e., if $q_\theta \neq \hat{q}_H$ *then* $\hat{\rho}(q_\theta) = 1$.

Given these beliefs, a sufficient condition for a strategy pair to form a separating equilibrium is that the following conditions for a separating equilibrium be satisfied:

$$NB_i(H,\hat{q}_i^H,0) \geq NB_i(H,q(H,0),1) \tag{4.a}$$

$$NB_i(L,\hat{q}_i^H,0) \leq NB_i(L,q(L,1),1) \tag{4.b}$$

In order to describe the set of separating equilibrium outcomes, it will be useful to define the following two sets:
$R_i^H = \{ q_i^* \in Q_i \mid NB_i(H,q_i^*,0) \geq NB_i(H,q(H,0),1)\}$, which describes the set of q_i that satisfies (4.a) and $R_i^L = \{ q_i^* \in Q_i \mid NB_i(L,q_i^*,0) \leq NB_i(L,q(L,1),1)\}$, which is the set of q_i that satisfies (4.b). The intersection of these two sets is given by $R^{SL} = \{ q_i \mid q_i \in R^L \cap R^H \}$.

The set of separating equilibrium outcomes is given by:

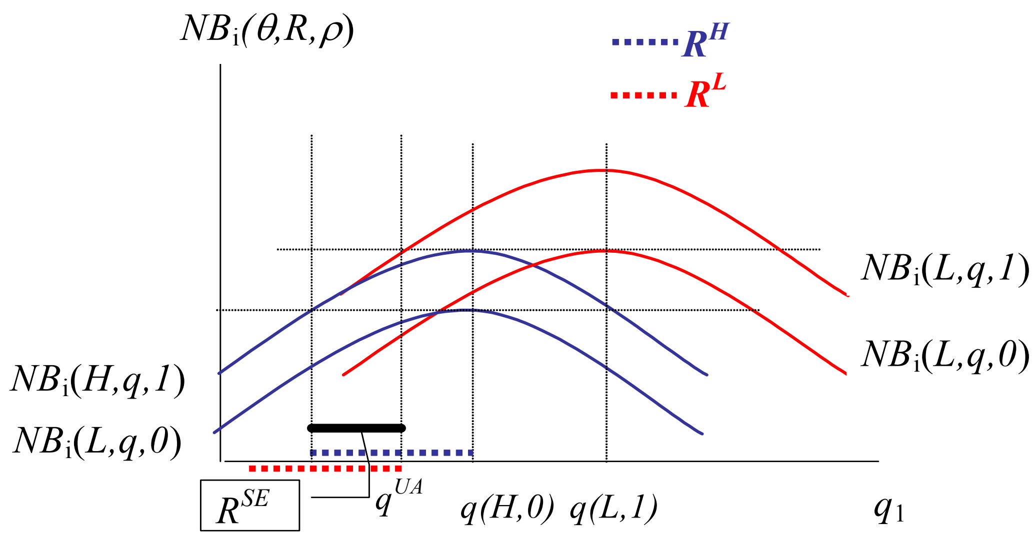
$$\hat{q}_i^H \in R^{SL} \tag{5.a}$$

$$\hat{q}_i^L = q_i(L,1) \tag{5.b}$$

Result 1: A separating equilibrium exists, if there exists a $q_i^{'} < q_i(H,0)$, such that $NB_i(H,q_i^{'},0) - NB_i(H,q(L,1),1) > NB_i(L,q_i^{'},0) - NB_i(L,q(L,1),1)$ Proof, see appendix 2.

The necessary condition says that it must be less costly for the high cost type than for the low cost type to decrease reductions below $q_i(H,0)$ defined by the condition in result 1. In this way it resembles a sorting condition well-known form the signalling literature. Figure 3 explains this condition. Typically, the set of separating equilibrium outcomes is large, and this shortcoming will be dealt with now by introducing equilibrium refinements.

Figure 3. The set of separating equilibrium outcomes



Equilibrium refinements used for signalling games are based on the notion of forward induction, which asserts that when rational players enter a game, they should, in evaluating strategies, reason from the beginning of the game-tree by using introspection, i.e., by examining who has an incentive to send possible out-of-equilibrium messages, and then revise beliefs accordingly. Given that it is common knowledge among the players that everyone engages in this introspection process, an implicit communication emerges. To see how refinements based on this idea work, imagine that a player picks a candidate equilibrium outcome and then reviews the beliefs about out-of-equilibrium information sets that sustain this outcome. The player then applies a refinement criterion that describes what constitutes a reasonable belief. If, by taking into account the reasonableness of these beliefs and believing that the other players do so too, at least one player has an incentive to deviate, then this outcome is no longer an equilibrium in the refined game.

The requirement for belief formation applied in this paper says that it should be common knowledge among rational players that they never play a strategy profile that a particular player has no incentive to play. We say that a strategy *q'* is weakly dominated by another strategy *q''* for type θ, if, no matter what beliefs the uninformed player could possibly hold after observing the move of the informed player, the expected payoff of playing *q''* always exceeds the expected maximum payoff of playing *q'* for the informed player.

Definition: Weakly dominated (WD) strategy: A strategy *q*' is WD by *q*'' for type θ, if $\min_\rho NB_i(\theta, q'', \rho) \geq \max_\rho NB_i(\theta, q', \rho) \Rightarrow P_i(\theta, q'', 1) \geq P_i(\theta, q', 0)$.

The definition says that even in the case where *q*'' is followed by the worst possible circumstances from the point of view of the informed player, this reduction level is still preferred to *q*', even when *q*' is followed by the best possible circumstances, then *q*' is weakly dominated for this type. We want to apply this requirement to reduce the set of separating equilibria, by invoking the following requirement.

Requirement on belief formation: If a signal *q*' is weakly dominated for one type θ, but not for the other type, then the uninformed players' belief should place zero probability that θ has sent *q*', i.e. *q*' must be followed by posterior $\rho(\theta|q')=0$.

Applying this relatively non-controversial requirement has tremendous cutting power on the set of separating equilibria, as stated now:

Result 2: There exist only one undominated separating sequential equilibrium, $(\hat{q}_i^L, \hat{q}_i^H) = (q_i(L,1), q_i^{UA})$. Proof, see appendix 2.

Result 2 is intuitive, since the H-type uses costly actions in order to try to separate from the shadow of the L-type. A rational player chooses this particular strategy, which implies the minimum necessary costs in order to separate, and, hence, the Pareto-optimal separating equilibrium is obtained implying the minimum possible distortion from the full information (first best) allocation.

Compared to Hoel (1991), unilateral actions are fully explained as a rational move to reveal that costs are high. However, from (2) and (3) it follows that although revelation of costs can increase the response of the other country, in this model it cannot be the case that, un-coordinated, both increase their reductions. Moreover, compared to what should be required for an action to serve as a 'good example', the action is in the wrong direction, since in our model, the high cost country reduces less in order to trigger an increase in the other countries' reduction. Most importantly, however, the unilateral actions do not 'set a good example' and do not establish any move forward solving the underlying environmental problem.

Proposition 1: In Hoel's (1991) model, simply adding private information about costs and allowing unilateral actions to reveal such costs does not result in 'setting a good example'.

Hence, the information structure of signalling game 1 does not yield a better prospect for unilateral actions than does the original analysis of Hoel (1991). The reason why the other countries reduce more in the non-cooperative setting is that country *i* reduces less, due to it having high costs, and hence, it strategically exploits information. In this respect this looks more like an act of free riding. The signalling game model 1 however shows what is needed in order for a unilateral move to 'set a good example'.

5. Information structure and correlation of costs

Consider the following information structure. Initially, the countries are at q^{nc}. No country wants to initiate further reductions. Costs of further reductions are uncertain, with probability ρ, θ=L and with probability (1-ρ), θ=H, but most importantly, costs are fully correlated between countries. This information structure is common knowledge to the countries. Next, a country undertakes an assessment of the costs of reductions and it is assumed that it gets fully, but privately, informed. If it is revealed that costs are low, the country will initiate full-scale unilateral actions, if those actions indisputably reveal that costs are low. If it is revealed that costs are high, no further reductions will be made if all other countries believe that costs are high (but it will make unilateral actions, if it could convince the other countries that costs are low). Given this information structure, it is possible to state conditions where unilateral actions are indeed profitable.

Formally, the following 4 assumptions are made regarding the information structure:

Assumption A1 (correlation of costs): The cost-parameter is fully correlated between countries, i.e. $\theta_i = \theta_j, \forall i, j \in I$.

Assumption A2 (assessment of costs): Any country i can get fully (but privately) informed about θ_i. The cost of doing so, is $D_i > 0$.

Assumption A3 (profitability of unilateral actions for one country):
a) Let $q(\rho^1) = q(\rho^2)$ for all $\rho^1 < \overline{\rho}$ and $\rho^2 < \overline{\rho}$ and let $\rho^o < \overline{\rho}$.
b) Let $\exists i \in I : NB_i(\rho, q_i(\rho), q_{-i}(\rho)) \leq NB_i(L, q_i(L), q_{-i}(L)) + D_i$ and
$\forall j \neq i : NB_j(\rho, q_j(\rho), q_{-j}(\rho)) \leq NB_j(L, q_j(L), q_{-j}(L)) + D_j$.

Assumption A4 (Information-transmission): No verification technologies exist.

The first assumption (A1) requires that the underlying cost parameter is fully positively correlated between countries. Does there exist international environmental problems where the costs of reductions are positively correlated between countries? This could be the case in situations, where, if a country takes unilateral actions, it has to implement measures that hereafter are also available to other countries. Examples of this are measures to reduce current CO_2 emissions. If the establishment of windmills and their integration into the conventional energy-system can be shown to be cheap, it will be cheap for every country that can use wind for energy production. If the switching from coal fired to natural gas fired power plants is revealed to be cheap, this can be used for any country that uses coal as it's fuel-input. The most classical example, which shows a case with positively correlated costs, and how their revelation enables further reductions, can be found in the efforts to control substances that deplete the ozone layer. In 1987, a breakdown in the negotiations over the Montreal Protocol seemed inevitable, but following the rapid development of acceptable (i.e., cheap) substitutes (in the US) producers had much to gain from a CFC-ban. Producers had no incentives to put up any political opposition to the Montreal protocol, and a breakthrough in the negotiations occurred.[11]

Although costs are not likely to fully positively correlated, for now, this is assumed, but the analysis could be thought of as being used to answer the following question: How does correlation of costs influence the likelihood of profitable unilateral actions? In section 7, it is analysed how changes in the correlation affects the likelihood of unilateral actions.

Assumption A2 says that a country become get fully informed about costs, without undertaking the actual reductions: To make our analysis tractable, it is simply (but somewhat unrealistically) assumed that it can be fully informed. We assume that the country incurs a fixed (sunk) cost of being informed. This could range all the way from detailed reports to the establishment of non-

11 Sandler, 1997, page 113.

polluting energy-supply system.[12] Again, we will analyse the effects of this assumption in section 7.

Assumption A3a means that at the current state of information, that for all $\rho < \overline{\rho}$, the reduction levels will remain unchanged. This assumption is needed in order for unilateral actions ever to be profitable, and can be justified by the fact that costs of reductions refers to further reductions. We offer a more convincing explanation in section 7. Given this assumption, A3b says that one and only one country has an incentive to gather information. One way of thinking of this is that at a given date, no country has such an incentive, but as time passes, cost and damage figures change, or the cost of becoming informed changes. (E.g. new scientific information reveals that damage costs are higher than expected.) All in all, the effect of this is assumed to be that at some date it is worthwhile for one country to become informed. In section 7 we offer an alternative explanation of how to identify the country that undertakes the unilateral actions.

Assumption A4 is probably the most critical assumption. The assumption means that although a country becomes fully informed about the common cost parameter, it cannot costlessly verify this information to the other countries. This can be justified by pointing out that, even if the country observes that costs are high, it has an incentive (now more than ever) to persuade the uninformed countries that costs are low, by misstating data, or any possible way of misinforming. This assumption is needed in order for a country to distinguish itself from the shadow of a high cost country by use of a costly signal (the full scale unilateral actions) that would never be profitable if it had high costs. We also offer an alternative set-up that, from a public choice point of view, gives a more detailed description of the mechanisms by which information is transmitted between countries.

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12 A more realistic approach is shown in Kessler (1998), where the more a country invests in the information gathering activity (which increases costs), the higher is the probability to become informed.

With these assumptions in place, we turn to the description of the signalling game that forms the basis for the unilateral actions, since we then assume that updates are dependent on observed levels of reductions only.

6. The signalling game 2: Incentives to signal that costs are low

The timing of events in the correlated model is as follows: Nature draws a (common) type θ from the set $\{L, H\}$, according to a probability distribution $(\rho, 1\text{-}\rho)$ where ρ=prob (θ=L). One country, denoted country i, makes an effort to reveal θ. Given this, this country is totally informed, whereas the other countries remain uninformed. Hereafter, this country chooses a reduction level $q_i \in Q_i$. The other countries $j \neq i$, observe q_j, but not θ, and choose their reduction level $q_j \in Q_j$. The net benefit functions are still $NB_i = NB_i(\theta, q_i, q_j)$, but now the type of the uninformed countries are determined by their posterior belief, hence $NB_j = NB_j(\rho(q_i), q_i, q_j(q_i, \rho(q_i)))$. Note that compared to the non-correlated situation, it is now the low cost country that needs to undertake costly efforts in order to separate.

Under what conditions can a low cost country reveal its true costs and get the uninformed to increase their reductions accordingly? First of all, a collection of reduction levels and beliefs $\{\hat{q}_H, \hat{q}_L, \hat{\rho}(q_i)\}$ forms a sequential equilibrium if the following conditions are satisfied:

i) Optimality for the country with costs θ:
$\hat{q}_\theta \in \arg\max NB_i(\theta, q_i, q_j(q_i, \rho(q_i))$

ii) Beliefs are Bayes-consistent:
a) If $\hat{q}_H \neq \hat{q}_L$ then $\hat{\rho}(\hat{q}_H) = 0$ and $\hat{\rho}(\hat{q}_L) = 1$
b) If $\hat{q}_H = \hat{q}_L$ then $\hat{\rho}(\hat{q}_H) = \hat{\rho}(\hat{q}_L) = \rho^o$

c) *If* $q_\theta \neq \{\hat{q}_H, \hat{q}_L\}$ *then* $\rho(q_\theta) = 0$

Regarding the beliefs again let any out-of-equilibrium moves be followed by the worst possible beliefs from the point of view of the informed country. This now means that $q_\theta \neq \hat{q}_L$ *then* $\hat{\rho}(q_\theta) = 0$. If costs turn out to be low, the informed country will try to convince the uninformed that costs are low. It can do so by unilaterally increasing its reductions to such an extent that only a low cost country could profit from such a move, even if beliefs are updated most favorably from the point of view of the informed country. If costs turn out to be low, the following two conditions are necessary for the low cost country to separate.

$$NB_i(L, q_i^{UA}, 1) \geq NB_i(L, q(L,1), 0) \quad (6.a)$$
$$NB_i(H, q_i^{UA}, 1) \leq NB_i(H, q(H,0), 0) \quad (6.b)$$

In order to describe the set of separating equilibrium outcomes, it is convenient to define the following two sets:

$$R_i^L = \{q_i^* \in Q_i \mid NB_i(L, q_i^*, 1) \geq NB_i(L, q(L,1), 0)\}$$
$$R_i^H = \{q_i^* \in Q_i \mid NB_i(H, q_i^*, 1) \leq NB_i(H, q(H,0), 0)\}$$

The intersection of these two sets is given by $R^{SC} = \{q_i \mid q_i \in R^L \cap R^H\}$. In order for the low cost type to accomplish this, assume the following single crossing condition (SCC): For all $\rho'' > \rho'$ and all $q^1, q^2 \in Q_i$: $NB_i(L, q_i^2, \rho'') - NB_i(L, q_i^1, \rho') > NB_i(H, q_i^2, \rho'') - NB_i(H, q_i^1, \rho')$. The SCC says that an increase in beliefs (beliefs that costs are higher), increases the NB more for a low cost country than for a high cost country.

The set of separating equilibrium outcomes is given by

$$\hat{q}_i^L \in R^{SC} \quad (7.a)$$

$\hat{q}_i^H = q(H,0)$ (7.b)

And will, under the given assumptions, always exist:

Result 3: Given the single crossing condition, there always exists a separating equilibrium given by (7.a) and (7.b). Proof, see appendix 2.

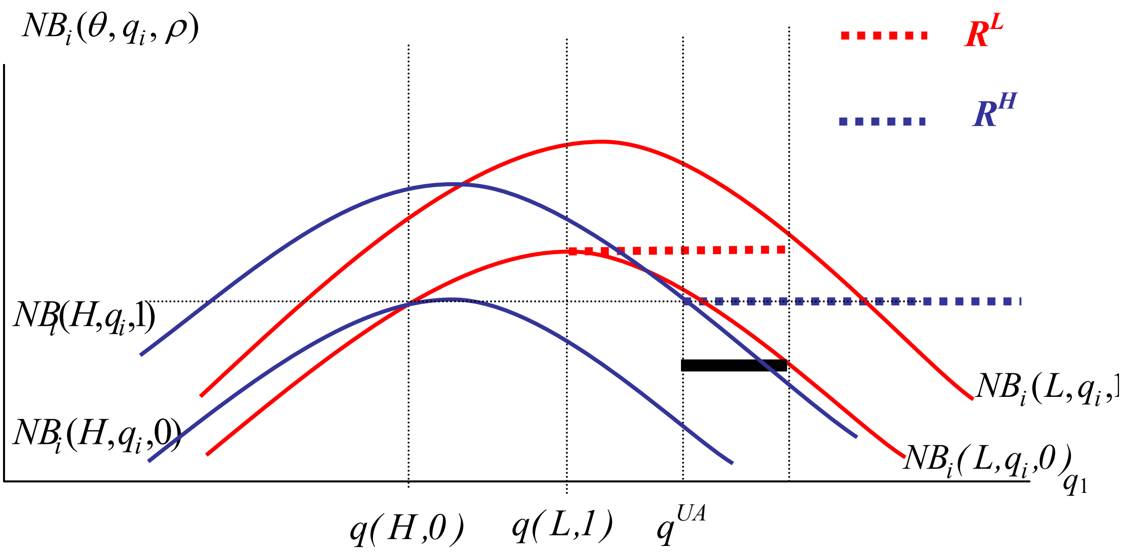
This result is reproduced in figure 4, where R_i^L and R_i^H are indicated by the dotted lines as defines above. The interception indicated by the bold line indicates the set of separating equilibrium outcomes, all representing an increase in reduction levels for the low cost compared to the full information situation.

Again, as in section 3, the requirement on belief formation will be that if a signal *q'* is weakly dominated for one type θ, but not for the other type, the uninformed players' belief should place zero probability that θ has sent *q'*, i.e. *q'* must be followed by posterior $\rho(\theta|q')=0$. The result of doing this is stated below:

Result 4: There exists one undominated separating equilibrium, $(\hat{q}_i^L, \hat{q}_i^H) = (q_i^{UA}, q(H,0))$, where $q_i^{UA} = \sup \arg\{q_i \in Q_i \mid NB_i(L, q_i, 1) = NB_i(L, q(L,1), 0)\}$.

Proof, see appendix 2

Figure 4.   The set of separating equilibrium outcomes



The main findings of this section the following proposition summarizes:

Proposition 2: Given A1-A4 and the SCC, when costs are fully correlated, but no country initially is informed about the true cost level, and a country can be fully informed, then $q_i^{UA} > q(L,1)$, $\hat{q}_i^H = q(H,0)$, and the response by the uninformed countries are also to increased reductions.

Hence, the reduction of each country is higher and in this case unilateral action clearly has a potential to move the countries' reduction levels in the right direction (seen both from an environmental and an economic point of view), compared to the result in Hoel (1991). Note that the reason for unilateral action is the inability of a low cost country to verify its costs unless it engages in costly activity that convinces the other countries about its true type. Hence, unilateral actions are a consequence of an adverse selection problem and the incentives (for a high cost type) to misrepresent the true costs. Note that given assumption A3a and A3b, it is also profitable for a country to undertake unilateral actions, and given A4, it is optimal to take unilateral actions, since there exists no other means of transmitting information than by the appropriate choice of q_i.

7. Relaxing the assumptions

The result stated in proposition 1 builds on a number of strong assumptions. This section is devoted to analyzing how the assumptions influence the probability of unilateral actions. First and foremost, it is interesting to investigate the role of the correlation of costs for the result in proposition 2. Let γ be the correlation, i.e. γ=1 means fully positive correlation. Common sense suggests that the higher the correlation, the more likely are unilateral actions. The analysis of this paper verifies this intuition.

Result 5: Given A2-A4, there exists a $\bar{\gamma} > 0$ such that for all $\gamma > \bar{\gamma}$, unilateral actions are profitable if costs are low, and for $\gamma \leq \bar{\gamma}$, unilateral actions are not profitable. Proof, see Appendix 2.

First, it is important to recognize that unilateral actions are more likely to be profitable the more a given increase in beliefs increases the response in terms of increased reductions. The reason for this is that a country will only engage in unilateral actions if the expected gain of doing so outweighs the costs of becoming informed. Note, however, that this is not an obvious conclusion. Both types prefer a high response and since unilateral actions are used by the low cost country to separate from the shadow of the high cost type, a higher response only makes unilateral actions more likely (i.e. separation more likely) when the low cost type profits more from a better response than does the high cost country. But this is exactly what the single crossing condition implies: The low cost country will need less costly effort to separate. Now it is easy to verify that the assumption of high correlation is important. If the informed country's signal is only an imperfect signal (imperfectly correlated costs), then the updating of beliefs will never reach 1. Hence, more reduction efforts are needed to get a response at all, and once the response appears, it is to a less extent. The higher the correlation, the more an increase in beliefs about the informed country will change expectations about own cost: The higher the correlation, the higher the response, and the more likely the unilateral move implying that the level of unilateral actions will be smaller in separating equilibria.

Regarding A2: If a country can only receive an imperfect signal about the costs, this reduces the profitability of unilateral actions, since the expected benefit of making the initial assessment decreases. The reason is that since there is now a risk that a country will mistakenly take unilateral actions although costs turn out to be high, it is more costly to initiate unilateral actions.

The curse of the initial mover

Result 6: The more likely that unilateral actions will be initiate,

a) The lower the estimated costs of getting informed,
b) The larger the expected response,
c) The higher the expected correlation.

Assumption A3 is needed in order for one country to undertake unilateral actions. Instead of letting D_i vary between countries, we could have that a country considering engaging in unilateral actions must form expectations about what the response of other countries will be. Assuming that countries hold different assessments about the reactions of the others, we get the following result:

Why do different countries hold different beliefs? Could it be that countries with high international environmental profiles believe that if they reveal that costs are not as high as expected, other countries will be convinced of the necessity to make larger reductions in emissions.[13] If so, then countries with

13 This hypothesis is based more on empirical evidence than on a theoretical foundation. The empirical evidence supporting it is best summarized by this quote from Rabin (1998, page 26): 'A range of research suggests that once forming strong hypotheses, people are often too inattentive to new information contradicting their hypotheses. The form of anchoring does not necessarily imply that people misinterpret additional evidence, only that they ignore additional evidence.

strong international environmental profiles will take unilateral actions, while countries with low such profiles will tend to make their strategies contingent on the actual achievements of other countries. This could also be supported by the presence of self-serving beliefs.[14] Taken together it says that countries that value environmental protection highly also tend to believe that other countries do. Hence, the country most likely to engage in unilateral action is the one that has the most positive perception (expectation) about the response in terms of increased reductions aboard. But this will have serious consequences for the country undertaking the unilateral actions. Since it has the highest estimate, the real size of the response is likely to be smaller, and, ex post, the unilateral actions will probably not be (as) profitable. This resembles the well-known phenomenon called the winner's curse from auction theory. This we restate as result 7.

Result 7: The curse of the country that initiates the unilateral action: *Since the country with the highest estimate of the others' response will initiate the unilateral action, this country is likely to over-estimate the actual response.*

Hence, in the end, the country undertaking the unilateral actions will be disappointed, and should consider updating its beliefs about the responses.

Alternative specification of the information structure

By changing the information structure, we have identified conditions where unilateral actions are profitable in the framework of Hoel (1991). We now offer an alternative specification of how information can be transmitted to other countries by use of a very simple public choice model. There are several reasons why we do this. One is that this removes the necessity of assumption A4 and yields a more convincing argument for assumption A3b. It moreover gives

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Psychological evidence reveals a stronger and more provocative phenomenon: people tend to misread evidence as additional support for initial hypotheses.

14 For a discussion of such beliefs, see Dahl and Ransom (1999).

a more satisfactory explanation for how "setting a good example" could be accomplished, why costs are correlated and how revelation of costs in one country changes incentives in other countries.

The alternative way of modelling the spillover effect on the level of environmental regulation in other countries is by taking into consideration the political process in the countries. An example will be presented below, building on a simple influential function approach inspired by Becker (1983).[15] We assume that the decision about the level of environmental regulation in a country is determined by the lobbing activities of two pressure groups: An industrial group (IG) lobbying for no reductions and an environmental group (EG) lobbying for high reductions.[16] The more pressure a group exerts, the more it influences the policy outcome. According to Svendsen (1998), the EG try to maximize their influence through maximizing membership. Increasing membership increases payments and, hence, enables these groups to increase their lobbing activities. One way of increasing membership is to convince potential members of the importance of a strong EG. By pointing to achievements in other countries and arguing that these results are a consequence of strong EGs the domestic EG has a strong argument that results in higher pressure on the decision-makers. On the other hand, an IG uses issues such as losses of international competitiveness and, consequent increases in unemployment and reductions in export as arguments against environmental regulation. The higher are the reduction costs, and the more severe the problems related to the IGs, the more weight will the IG's arguments receive in the decision.

In order to integrate this public choice model into the signalling model, we must still require that q_i is the outcome of a maximizing process. This requires a reinterpretation of the cost and benefit functions associated with reducing emis-

15 See also Potters and Sloof (1996) for a survey of this type of model.

16 That lobbyism influences the decisions of policy-makers is well documented. Svendsen (1998) mentions that all eight existing US permit marked programs have been distorted politically through lobby activities. Haas, Keohane and Levy (1993) note that if there is one key variable accounting for policy change, it is the degree of domestic environmentalist pressure in major industrialized democracies, and not the decision making rules of the relevant institution.

sions in expression [1]. One proposal is as follows: define a country's wealth (utility) connected with the emission as $w_i = \lambda u^{IG}(q_i, c_i) + (1-\lambda)u^{EG}(q)$. Wealth in country i is given by $w_i(q_i, q, c_i)$. Given this specification, define now $q_i^{nc} = \arg\max w_i((q_i, q, c_i)$. Given the discussion above, we have that

$$\frac{\partial q_i^{nc}}{\partial \rho_i} < 0 \text{ and } \frac{\partial q_i^{nc}}{\partial q_{-i}} > 0 .$$

From the above discussion, we immediately derive that $\frac{\partial\left(\frac{\partial u_i^{IG}}{\partial q_i}\right)}{\partial c_i} > 0$ and $\frac{\partial\left(\frac{\partial u_i^{EG}}{\partial q}\right)}{\partial c_i} = 0$. The higher the costs, the more the IG suffers if it has to make reductions, and the more this group is willing to lobby against reduction (the marginal gain from lobbying is increasing in *c*). On the other hand, the EG is suffering from global emissions, but the level of costs has no effect on the utility of the EG.[17]

In this way q_i is chosen as the welfare maximizing choice of country i (as a trade-off between conflicting preferences of two influential interest groups, and in optimum balancing the benefit to the EG of the reductions with the costs of doing so for the IG).

In all countries, where the political decision process is as described above, the industry has incentives to try to make policy makes believe that costs are high. Compared to the model in section 5, this better explains the assumption about the high correlation of costs. Since the correlation is related to the political systems in a country. Given identical political systems, the incentives to believe that costs are high are also identical. It, moreover, also better explains how the

17 Other specifications could be used, but what is important is how the cost estimates influence a country's choice of reductions.

emergence of new information can trigger positive responses in all these countries.[18]

This model can also be used to motivate why countries initially do not reduce (or reduce as if costs of further reductions are high). Assume that for $\rho^o \in [0,\bar{\rho}]$ a country will not engage in any reduction efforts. A reason for this could be that as long as costs are believed to be high with a high probability, then the IG will have almost full discretion over national policy (the marginal gain from pressure from the IG is relatively high). Consequently, the IG will put sufficiently high pressure against national reductions such that this country acts as a high cost country.[19] Importantly, though, as long as the government has no incentives to become informed, which is the case as long as its estimates of others' responses are not sufficiently high, we know from section that the decision makers have good incentives to accept claims (e.g. from home industry) that costs are high. When a government has a pretty clear picture of the costs, then it needs an extremely high effort from the IG to change this picture. The chain of arguments goes as follows: Initially, the country holds a prior belief about its own costs and others' costs and the pressure from the IG to make no reductions is relatively effective, since $\bar{\rho} < \rho^o$. Now, the other country makes a cost revealing move and costs are low. The higher the correlation of costs, the more 'informed' the government becomes, and the less is the marginal effect of the pressure from the IG, in which case the pressure is reduced and the national reduction is increased.

Finally, let us combine all the insights gained in this paper. Simply letting unilateral actions be motivated by revelation of costs is not enough to get a satisfactory explanation of unilateral actions. If reduction costs are correlated then the transmission of information by use of a unilateral move makes sense. The prospects of unilateral actions are enhanced if we re-model the determination of policy choices. When such choices are made on the basis of messages received

18 This could, e.g., be the case for western democracies.

19 An example is the US policy on climate change issues, where the relatively high probability of high costs has been given as the main reason against any reduction effort.

from influential IGs, then unilateral actions by one country can change the effect of such messages. However, unilateral actions have not always been as successful as expected. One explanation offered in this paper is that the initiator of unilateral actions is the country with the highest expectation about its prospects of influencing other countries' decision processes. Since the country holding the highest expectation is likely to overestimate the true state, it is likely to be disappointed. In conclusion, this paper both provides positive and negative prospects for the initiator of unilateral actions as movements towards an effective control of the international environmental problem.

8. Conclusions

The analysis presented in this paper builds on the crucial assumption that unilateral actions concern the revelation of information about the cost side. Is it reasonable to expect that uncertainty relates to the cost side and not the damage side? We believe that taking unilateral actions reveals the true costs. Once relevant measures are implemented, information regarding their efficiency and their costs are available. On the other hand, a unilateral action will not reveal the damage costs (or equally, the benefits from reductions). In particular, if considering a global pollution problem, the effect of one country on the total stock of pollution will probably be negligible, and no new information regarding the damage cost functions is revealed. Moreover, compared to the model in section 5, taking into account the public choice model, unilateral actions as a cost revealing mechanism becomes even more likely: If we look at the problems of implementing the Kyoto-agreement, the US policymakers repeatedly claimed that the costs of reductions were simply too high to justify the efforts can. Such a statement can only be undermined if it is revealed that also for US costs of reductions are low. We also believe that signalling as a mechanism of information transmission in the way described in this paper is not unreasonable. The reason is that countries are only convinced by hard facts (and not by a report from a government hired consultancy agency), simply because incentives are such that each country has an incentive to try to convince others that costs are low. However, only when a country has verified that costs are low by implementing the necessary measures, that is, by engaging in full-scale unilateral actions, can it possibly convince the other countries. But why is this an efficient means of transmission.

Another reason to undertake unilateral actions is the expectation of achieving a first mover advantage. The existence of such advantages clearly enhances the prospect of unilateral actions. In particular, the way unilateral actions are modelled in this paper, where it is assumed that a country actually undertaking the necessary reduction measures, this country clearly has a first mover advantage. In this case a country could reveal that costs are low, trigger higher reductions in other countries and at the same time increase the potential of the first mover advantages by enabling large-scale export possibilities. A country that engages in unilateral actions could also make its move more profitable by engaging in activities that yield first mover advantages. For example, in Denmark national subsidies of the windmill industry could turn out to be extremely profitable if a significant reduction of CO_2 emissions is initiated globally.

It has been argued that the emergence of substitute substances for CFC gasses changed certain EU countries' strategies in the run-up to the Montreal protocol, from being reluctant participants to taking the lead. If we include first mover advantages, the conclusion about the curse of the initiator of unilateral actions might no longer be valid. The reason is that if first mover advantages vary (or are highly distinct) for the countries, then even if a country does not have high expectations (compared to some average for the countries) it might still initiate unilateral actions that also ex post turn out to be profitable.

9. Literature

[1] Barrett, S.(1990), International Environmental Agreements as Games, in R. Pethig, ed., *Conflicts and Cooperation in Managing Environmental Resources*. Springer-Verlag, Berlin.

[2] Barrett, S. (1994), 'Self-Enforcing International Environmental Agreements', *Oxford Economic Papers*, **46**, 878-894.

[3] Barrett, S. (1998), 'Political Economy of the Kyoto Protocol', *Oxford Review of Economic Policy*, **14**, 4, 20-39.

[4] Becker, G (1983), 'A Theory of Competition Among Pressure Groups for Political Influence', *Quarterly Journal of Economics*, **98**, 371-400.

[5] Brandt, U.S. (2002), 'Actions Prior to Entering an International Environmental Agreement', *Journal of Institutional and Theoretic Economics*, ***158**, 695-714.*

[6] Dahl, G. B. and M. R. Ransom (1999), 'Does Where You Stand Depend on Where You Sit? Tithing Donations and Self-Serving Beliefs', *The American Economic Review*, **89**, 703-728.

[7] Dijkstra, B. R. (1999), *the Political Economy of Environmental Policy*, Edward Elgar Publishing Ltd, Cheltenham, U.K.

[8] Finus, M. (2001), *Game Theory and International Environmental Cooperation*, Edward Elgar Publishing Ltd, Cheltenham, U.K.

[9] Hoel, M. (1991), 'Global Environmental Problems: The Effects of Unilateral Actions Taken by One Country', *Journal of Environmental Economics and Management*, **20**, 55-70.

[10] Hoel, M. (1997), 'Coordination of Environmental policy for Transboundary Environmental Problems?'. Journal of Public Economics, 66, 199-224.

[11] Hermalin, B. E. (1998), 'Toward an Economic Theory of Leadership: Leading by Example', The American Economic Review, 88, 1188-1206.

[12] Kessler, A. S. (1998), 'The Value of Ignorance', *The Rand Journal of Economics*, **29**, 339-355.

[13] Haas, P. M., R. O. Keohane and M. A. Levy (1993), *Institutions for the Earth: Sources of Effective International Environmental Protection*, MIT Press, Cambridge, MA.

[14] Rabin, M. (1998), 'Psychology and Economics', *Journal of Economic Literature*, **36**, 11-46.

[15] Potters, J. and R. Sloof (1996), 'Interest Groups: A Survey of Empirical Models that Try to Assess their Influence', European Journal of Political Economy, 12, 403-442.

[16] Sandler, T. (1997), *Global Challenges, an Approach to Environmental, Political and Economic Problems,* Cambridge University Press.

[17] Svendsen, G.T. (1998), *Public Choice and Environmental Regulation: Tradable Permit Systems in United States and CO_2 Taxation in Europe*, New Horizons in Environmental Economics, Edward Elgar, Cheltenham, U.K.

[18] Tirole, J. (1998), *The Theory of Industrial Organization,* MIT Press, Cambridge, MA.

[19] Varian, H. R. (1992), *Microeconomic Analysis*, W.W. Norton, New York.

10. Appendixes

Appendix 1

$NB_i = B_i(q_i, q_j) - C(q_i)$, $\mathrm{i} = 1{,}2$.

$B_i^{'}(q) > 0$ and $B_i^{''}(q) < 0$ while $C_i^{'}(q_i) > 0$ and $\mathrm{C}_i^{''}(q_i) > 0$.

Comparative static. Suppose that *a* is some parameter that shifts the net benefit function of country 1. The Nash equilibrium is described by the conditions:

$$\frac{\partial NB_1(q_1(a), q_2(a), a)}{\partial q_1} = 0$$

$$\frac{\partial NB_2(q_1(a), q_2(a))}{\partial q_2} = 0$$

Differentiating these equations with respect to *a* gives us the system

$$\begin{pmatrix} \dfrac{\partial^2 NB_1}{\partial q_1^2} & \dfrac{\partial^2 NB_1}{\partial q_1 \partial q_2} \\ \dfrac{\partial^2 NB_2}{\partial q_1 q_2} & \dfrac{\partial^2 NB_2}{\partial q_2^2} \end{pmatrix} \begin{pmatrix} \dfrac{\partial q_1}{\partial a} \\ \dfrac{\partial q_2}{\partial a} \end{pmatrix} = \begin{pmatrix} -\dfrac{\partial^2 NB_1}{\partial q_1 \partial a} \\ 0 \end{pmatrix}.$$

Applying Cramer's rule, we have

$$\frac{\partial q_1}{\partial a} = \frac{\begin{vmatrix} -\dfrac{\partial^2 NB_1}{\partial q_1 \partial a} & \dfrac{\partial^2 NB_1}{\partial q_1 \partial a} \\ 0 & \dfrac{\partial^2 NB_2}{\partial q_2^2} \end{vmatrix}}{\begin{vmatrix} \dfrac{\partial^2 NB_1}{\partial q_1^2} & \dfrac{\partial^2 NB_1}{\partial q_1 \partial q_2} \\ \dfrac{\partial^2 NB_2}{\partial q_1 q_2} & \dfrac{\partial^2 NB_2}{\partial q_2^2} \end{vmatrix}}.$$

Assume that the denominator is positive (due to uniqueness and slope, see Varian (1992) p 288-289).

The sign of the denominator is determined by

$$-\frac{\partial^2 NB_1}{\partial q_1 \partial a}\frac{\partial^2 NB_2}{\partial q_2^2}$$

The second term is negative (NB is concave in q), hence, we have that

$$\text{sign}\frac{\partial q_1}{\partial a} = \text{sign}\frac{\partial^2 NB_1}{\partial q_1 \partial a}.$$

We are, however, more interested in

$$sign\frac{\partial q_2}{\partial a}.$$

$$\frac{\partial q_2}{\partial a} = \frac{\begin{vmatrix} -\dfrac{\partial^2 NB_1}{\partial q_1 \partial a} & \dfrac{\partial^2 NB_1}{\partial q_1^2} \\ 0 & \dfrac{\partial^2 NB_2}{\partial q_1 q_2} \end{vmatrix}}{\begin{vmatrix} \dfrac{\partial^2 NB_1}{\partial q_1^2} & \dfrac{\partial^2 NB_1}{\partial q_1 \partial q_2} \\ \dfrac{\partial^2 NB_2}{\partial q_1 q_2} & \dfrac{\partial^2 NB_2}{\partial q_2^2} \end{vmatrix}}.$$

Assume that the denominator is positive (due to uniqueness and slope, see Varian (1992) p 288-289).

The sign of the denominator is determined by

$$-\frac{\partial^2 NB_1}{\partial q_1 \partial a}\frac{\partial^2 NB_2}{\partial q_1 q_2}.$$

Since q_1 and q_2 are strategic complements, i.e.

$$\frac{\partial^2 NB_2}{\partial q_1 q_2} > 0.$$

The second term is positive, and we have that

$$\text{sign}\,\frac{\partial q_2}{\partial a} = \text{sign}\,-\frac{\partial^2 NB_1}{\partial q_1 \partial a}.$$

And

$$\text{sign}\,\frac{\partial q_1}{\partial \theta_1} = -\text{sign}\,\frac{\partial q_2}{\partial \theta_1}.$$

Changes in country 1's costs, i.e. let *a*=*c*$_1$.

Effect on q_1.

$$\text{sign}\,\frac{\partial q_1}{\partial a} = \text{sign}\,\frac{\partial^2 NB_1}{\partial q_1 \partial a}.$$

Evaluate

$\frac{\partial^2 NB_1}{\partial q_1 \partial \theta_1} = -q_1 < 0$, in our model.

Hence,

$\frac{\partial q_1}{\partial \theta_1} < 0$ and $\frac{\partial q_2}{\partial \theta_1} > 0$.

The intuition is that when country 1's costs increases, this leads to smaller reductions by country 1, smaller reductions increase the marginal benefit for country 2 of the same level of reductions, and, hence, it will reduce more in response.

Appendix 2

Proof of result 1: We will show that a $q_i^{'} < q(H,0)$ exists that satisfies both 4.a and 4.b. Define $q_i^{'} = \min\arg\{NB_i(L,q_i,0) = NB_i(L,q(L,1),1)\}$, i.e. $q_i^{'}$ is the smallest q_i satisfying 4.b. If at the same time, $q_i^{'}$ satisfies 4.a with strict inequality, then existence is guaranteed. Given that $NB_i(H,q_i^{'},0) > NB_i(H,q(H,0),1)$, then also $NB_i(H,q_i^{'},0) > NB_i(H,q(L,1),1)$, since $q(H,0)$ is the unique maximizer of $NB_i(H,\rho,0)$.

From this we have that $NB_i(H,q_i^{'},0) - NB_i(H,q(L,1),1) > NB_i(L,q_i^{'},0) - NB_i(L,q(L,1),1)$. Hence, in order to get separation, there must exist a $q_i^{'} < q_i(H,0)$, such that $NB_i(H,q_i^{'},0) - NB_i(H,q(L,1),1) > NB_i(L,q_i^{'},0) - NB_i(L,q(L,1),1)$.

Proof of result 2: Weak domination for the low cost type in this set-up corresponds to the following inequality. If $NB_i(L,q(L,1),1) \geq NB_i(L,\hat{q}_i,0)$, then all $\hat{q}_i$ are weakly dominated by $q(L,1)$. But this expression is equal to 3.2, the condition satisfied by all separating equilibria. Hence, all $\hat{q}_i$ are weakly dominated by $q(L,1)$ for the low cost type.

Define $\overline{q}_i^H = \min\arg\{NB_i(H,\hat{q}_i^H,0) = NB_i(H,q(H,0),1)\}$. We now show that no $\hat{q}_i^H \neq \overline{q}_i^H$ is weakly dominated. This amounts to showing that

$NB_i(H,\hat{q}_i^H,0) > NB_i(H,q(H,0),1)\}$. Use 3.1. $NB_i(H,\hat{q}_i^H,0) \geq NB_i(H,q(H,0),1)$ and the fact that $NB_i(H,\hat{q}_i,0)$ is decreasing in q_i for $q_i>q(H,0)$, for any $\hat{q}_i^H = \overline{q}_i^H - \varepsilon$, 3.1 holds with strict inequality. Hence, no $\hat{q}_i^H \neq \overline{q}_i^H$ can be weakly dominated. Therefore, given $\hat{q}_i^H = \overline{q}_i^H - \varepsilon$, posterior beliefs will be updated to $\rho(\hat{q}_i^H) = 0$, and consequently, given this new set of beliefs, only $\hat{q}_i^H = \overline{q}_i^H$ is an undominated separating equilibrium.

Proof of result 3: Define $q_i^{'} = \sup\arg\{NB_i(H,q_i,1) = NB_i(H,q_i(H,0),0)\}$. If there exists a $q_i^{'}$ satisfying 6.a with strict inequality, then existence is guaranteed. If $NB_i(L,q_i^{'},1) > NB_i(L,q_i(L,1),0)$, then also $NB_i(L,q_i^{'},1) > NB_i(L,q_i(H,0),0)$, since $q_i(L,1)$ is the unique maximizer of $NB_i(L,q_i,\theta)$, which implies that if there exists a $q_i^{'} > q_i(L,0)$, such that

$NB_i(L,q_i^{'},1) - NB_i(L,q_i(L,0),0) > NB_i(H,q_i^{'},1) - NB_i(H,q_i(H,0),0)\}$, then a separating equilibrium exists. But this is guaranteed via the single crossing condition.

Proof of result 4:
Weak domination of $\hat{q}_i^H$ for the high cost type in this case corresponds to the following inequality:

$\max_p NB_i(H,\hat{q}_i^H,\rho) \leq \min_\rho\{NB_i(H,q_i(H,0),\rho),\}$ =>
$NB_i(H,\hat{q}_i^H,1) \leq NB_i(H,q_i(H,0),0)$, which is implied by 6.b.

Define $\overline{q}_i^L = \max\arg\{NB_i(L,\hat{q}_i^L,1) = NB_i(L,q_i(L,0),0)\}$. We now show that no $\hat{q}_i^L \neq \overline{q}_i^L$ is weakly dominated. This amounts to showing that $NB_i(L,\hat{q}_i^L,1) > NB_i(L,q_i(L,0),0)$. Use 6.a. $NB_i(L,\hat{q}_i^L,1) \geq NB_i(L,q_i(L,0),0)$ and the fact that $NB_i(L,q_i,\rho)$ is decreasing in q_i for $q_i>q_i(L,1)$, for any $\hat{q}_i^L = \overline{q}_i^L + \varepsilon$ 6.b holds with strict inequality. Hence, no $\hat{q}_i^L \neq \bar{q}_i^L$ can be weakly dominated. Therefore, given an $\hat{q}_i^L = \bar{q}_i^L + \varepsilon$, posterior beliefs will be updated to $\rho(\hat{q}_i^L) = 1$, and consequently, given this new set of beliefs, only $\hat{q}_i^L = \bar{q}_i^L$ is an undominated separating equilibrium.

Proof of result 5: First we note that if γ=0, then UA is not relevant (result 1 and 2) in the sense that a unilateral increase in reductions by one country will not increase reductions abroad. On the other hand, given proposition 2, given γ=1, UA is profitable. From (4) we have that $\frac{\partial[q_j(q_j^{UA}) - q_j(\rho)]}{\partial\gamma} > 0$, which says that the higher the correlation, the more the other countries will increase their reductions (i.e. the larger will be $q_j(q_j^{UA}) - q_j(\rho)$). Next, due to the SCP, $\frac{\partial q_i^{UA}}{\partial\gamma} < 0$. Hence, increased γ implies less UA is needed to get a higher response, and hence, $\frac{\partial NB_i(q_i^{UA}, q_j(q_j^{UA}))}{\partial\gamma} > 0$. Q.E.D.

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