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

Potential Failure of an International Environmental Agreement under Asymmetric Information

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Abstract

The free−riding issue is generally considered to be the biggest obstacle in the success of an international environmental agreement. Even without free−riding incentives, however, asymmetric information can pose a potentially significant threat in establishing a cooperative relationship. In this note, we examine perfect Bayesian equilibria of a simple signaling game between a polluter country and a victim country over an agreement to mitigate unidirectional transboudary pollution. We show that the stalemate in addressing an international environmental issue can be explained partly by the incentive conflict due to asymmetric information on the environmental preference of a polluter. We also identify several conditions that allow such a stalemate to occur more easily.

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1. Introduction

As a general principle to solve international environmental conflicts where polluters and victims are easily identified, many nations have agreed to the so-called Polluter Pays Principle where a polluter should take full or, at least, partial responsibility for the environmental damages that it inflicts upon other nations. Without a proper institution to enforce this principle, however, any international agreement has to be established on a voluntary basis. Hence, economists have advocated the application of the Victim Pays Principle as a more pragmatic approach to alleviate transboundary pollution under the current international circumstances (e.g., Baumol and Oates 1988).

In reality, however, it is quite rare to observe a large-scale side payment from a victim in order to combat transboundry pollution. There have been several previous studies to explain why we rarely observe such international transfer provision even in simple unidirectional pollution from one polluter to one victim.[1] The aim of this note is to present another possible explanation for the scarcity of cooperative relationships based on side payments in unidirectional pollution problems. Its main thesis is that asymmetric information about the environmental damage cost that a polluter incurs from its own emissions can be a source of difficulty in establishing such a relationship. Even though physical environmental damages of a polluter can be somehow observable to a victim, the polluter's evaluation of its damages would be very difficult to infer from outside.

To an economic problem with a hidden characteristic, the idea of the "revelation principle" has been widely applied (Fudenberg and Tiorle 1991). For unidirectional pollution with asymmetric information on a polluter's damage cost, this principle essentially implies that a victim can come up with a certain menu of various contracts, each of which is intended for a particular type of the polluter, and that allowing the polluter to voluntarily choose his favorite contract will, in fact, result in the revelation of its true type and the highest possible welfare for the victim, even though some information rent will usually accrue to the polluter, depending on its actual type. In each contract, the amount of side payment from the victim and the polluter's abatement level in the agreement is clearly specified. Then, a contract is immediately agreed by the two parties to implement, which does not explain the observed infrequency of international agreements with side payments. In our model, the offer of this sort of two-dimensional

[1] Mäler (1990) contends that too great willingness to provide a side payment may give this country a reputation as a "weak" negotiator and increase the costs of other agreements. Another possible explanation would be the existence of transaction cost that works against any kind of international agreement. Also, it has been pointed out that considering a transboundary environmental issue and other international relations at the same time could lead to a situation where a cooperative relationship can be more easily attained, even in the absence of a side payment (Cesar and de Zeeuw 1995).

contract is not allowed, which seems to be the case of the ongoing negotiations on global warming. The target emission level of each country has been predetermined in the Kyoto protocol while the amount of side payment is still under debate.

After describing our game model in the next section, we discuss its equilibria and their properties in the subsequent section.

2. Model

In order to focus on the issue with asymmetric information rather than the "free-ride" problem which could arise among multiple polluters or victims, we assume that there are only one polluter and one victim in this unidirectional pollution problem. Let e be the level of pollutant abatement effort made by the polluter.[2] Without the loss of generality, we restrict our attentions to a very tractable case of a quadratic abatement function for a polluter and linear damage cost functions for the two countries.[3] We suppose that the possible types of the polluter's damage cost are limited to two types, and, moreover, that the difference between these two types is entirely represented by the difference in the slopes of these damage cost functions. Specifically, the damage cost function of the polluter with type i, $DC_p^i(e)$, is defined as

$$DC_p^{\,i}(e) = \theta_i(e_p^{\,u} - e). \tag{1}$$

Here, θ_i is either θ_L or θ_H ($\theta_H > \theta_L$), depending upon its types, and e_p^u is the abatement level above which the pollutant emissions become completely harmless for both types of the polluter. The actual value of the parameter, θ_i, is privately known to the polluter, and the victim has an *ex ante* probability distribution regarding the type of the damage cost function of the polluter. This "prior belief" is defined such that the victim originally expects to face the low damage type and the high damage type with the probability of p ($0 < p < 1$) and $1-p$, respectively. We assume that this belief is common knowledge.

On the other hand, the damage cost function of the victim, $DC_v(e)$, is expressed as

$$DC_v(e) = d(e_v^{\,u} - e). \tag{2}$$

Similarly to e_p^u above, e_v^u is the polluter's abatement level above which the pollutant emissions are harmless for the victim. The parameter d is a constant and known by both countries. Furthermore, we suppose $d \geq 2(\theta_H - \theta_L)$, i.e., the damage cost of the victim is at

[2] We assume that pollutant emissions in the victim country are completely contained for simplicity.
[3] Our main results hold true as long as the polluter's abatement cost function is increasing and strictly convex in e and the damage cost functions of the victim and the polluter are both decreasing and convex in e.

least twice as large as the difference in the damage costs of the two polluter's types. As we will see below, otherwise there is a possibility that a negative amount of side payment is offered by the victim and accepted by the high cost type polluter in the equilibrium.

Finally, the abatement cost function of the polluter, $AC(e)$, is expressed as

$$AC(e) = \frac{1}{2}ce^2, \tag{3}$$

where c is a known constant. We suppose that c is sufficiently large so that the level of abatement efforts will not reach e_p^u or e_v^u under any circumstance. Then, due to the linear specification of the damage cost function, these values actually become insignificant in our analysis. For these simply specified set of functions, we can easily derive the corresponding "marginal" functions. Let us denote the marginal abatement cost function by $MAC(e)$, and the negatives of the marginal damage cost functions of the victim and the polluter by $MDC_v(e)$ and $MDC_p^i(e)$ (the superscript i signifies the polluter's type and $i = L$ or H), respectively.[4] Figure 1 depicts these marginal cost curves.

If there is complete information on the type of the polluter, we can easily identify its truthful abatement level in the non-cooperative situation, where the polluter takes only its own cost into account, as the level that minimizes the sum of its abatement and damage costs, i.e., $DC_p^i(e) + AC(e)$. Such an abatement level can be implicitly given by the usual marginal condition, which is $MAC(e) = MDC_p^i(e)$.[5] On the contrary, the internationally optimal abatement level or the abatement level in the cooperative case, where the damage cost of the victim is added to the consideration, is given by $MAC(e) = MDC_p^i(e) + MDC_v(e)$. This is simply a variation of the "Samuelson condition" for the provision of a public good.

The four abatement levels, e_N^L, e_N^H, e_C^L and e_C^H, in Figure 1 are respectively the non-cooperative abatement levels and the cooperative abatement levels for the two different types of the polluter, and they are obtained through the corresponding marginal conditions. Given our functional forms, the non-cooperative abatement level of the polluter in the absence of a side payment can be derived as $e_i^N = \theta_i/c$ for $i = L$ or H. On the other hand, the cooperative abatement level can be derived as $e_i^C = (\theta_i+d)/c$ for $i = L$ or H.

Now, we model our problem as a simple signaling game.[6] The game tree in Figure 2 depicts strategic interactions between the polluter and the victim. As is well known in the game theory literature, a game of incomplete information can be transformed with the introduction of an initial move by "Nature" to a game of imperfect information (Harsanyi

[4] In other words, $MDC_v(e)$ and $MDC_p^i(e)$ signify the values of environmental damages avoided by one additional unit of abatement effort.
[5] These marginal conditions are not only necessary but also sufficient for cost-minimization.
[6] For game-theoretic concepts used in this note, see Fudenberg and Tirole (1991).

1967). An important restriction of this transformation in our context is that the victim's prior belief on the polluter's damage cost must be common knowledge. With this transformation, Nature moves initially to determine the type of the polluter's domestic damage cost. Knowing this Nature's move, the polluter at the node P_L^0 or P_H^0 makes an announcement regarding its non-cooperative level of abatement. Here, we assume that this announcement is committed in the sense that the polluter has to implement the chosen non-cooperative abatement level without any assistance in case that the agreement is not eventually reached.[7] We will discuss the alteration of this assumption later.

After this action of the polluter, the abatement level in the international agreement is determined so as to maximize the global gain from the agreement according to the announced non-cooperative abatement level by the polluter. That is, the cooperative or internationally optimal level of abatement identified above is selected as the abatement level in a potential agreement. We assume that this decision is made exogenously by an outside agency or through a separate negotiation between the two countries. Then, the victim chooses the amount of side payment, s, which will be offered to the polluter in exchange for attaining the cooperative abatement level. Finally, the polluter chooses either to accept this offer of a side payment or to reject it. In case of its acceptance, the two countries engage in the international agreement which implies the implementation of the corresponding cooperative abatement level by the polluter and the provision of the side payment by the victim. In case of its rejection, the polluter implements its announced non-cooperative abatement level without any assistance from the victim.

The respective payoffs for the two countries in Figure 2 are obtained by calculating the corresponding areas in Figure 1. Let us denote the total costs for conducting the truthful non-cooperative abatement levels by α for the low cost type and by β for the high cost type, i.e., $DC_p{}^L(e_L{}^N) + AC(e_L{}^N) = \alpha$ and $DC_p{}^H(e_H{}^N) + AC(e_H{}^N) = \beta$.[8] On the other hand, we evaluate the victim's payoffs by supposing that its welfare level at $e_L{}^N$ is standardized to zero. These assumptions are innocuous as long as the payoffs in all the other situations are based on these benchmarks for both type of the polluter and for the victim. Let us also denote θ_H - θ_L by θ for the sake of notational convenience. The left and right entries in each parenthesis in Figure 2 are the payoffs of the polluter and the victim, respectively.

In our setup, the choice of e_H by the polluter essentially reveals that it is the high cost type since the low cost type would never choose e_H at the node P_L^0. This is because the low cost type polluter can secure itself the payoff of α by choosing e_L while it would only

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[7] Equivalently, the announcement can be made concerning its own damage cost as long as its non-cooperative abatement level of the polluter is based on this announcement when an agreement eventually fails.

[8] Since both α and β signify costs, these values are negative in terms of the polluter's payoffs.

obtain $\alpha - \theta(\theta+2d)/2c$,[9] when it is required to abate up to e_H^C and the victim provides the side payment that would leave the high cost type polluter just break-even at β, which is represented by the area (b+f+g) in Figure 1. Hence, the interaction after the choice of e_H, i.e., after the information set V_H is reached, is straightforward. By contrast, the high cost type has an incentive to lie and choose e_L at the node P_H^0 because of the possibility that it is treated as the low cost type and required to abate only up to e_L^C with the side payment that would leave the low cost type polluter just break-even at α. Such a side payment yields the high cost type polluter a strictly greater payoff than β by the area (a+c), which is obtained by subtracting the area (b) from the area (a+b+c) in Figure 1.[10]

3. Equilibria and Their Properties

In fact, mere consideration of the victim's belief at the information set V_L in Figure 2 suggests that we do not have a "separating" equilibrium where both types of the polluter act honestly at their initial nodes. Let us suppose that, when the information set V_L is reached, the victim believes that the polluter is the low cost type with the probability r ($0 \leq r \leq 1$) and it is the high cost type with the probability $1-r$. If both types of the polluter behaves honestly, the consistency of the victim's posterior belief specifies $r = 1$. Then, the victim will offer the side payment that leaves the low cost type just break-even. However, such an amount of side payment will induce the high cost type to switch its strategy and choose e_L^N, thus annihilating the possibility of this separating equilibrium.

As demonstrated in the appendix, we can derive two different kinds of perfect Bayesian equilibria, depending on the prior belief of the victim concerning the polluter's type. The first is a "hybrid" or "semi-separating" equilibrium which occurs when $p < 2\theta/(d+2\theta)$. In this equilibrium, the high cost type polluter employs the mixed local strategy as its initial move, randomizing between e_L^N and e_H^N with the probabilities $u = dp/2\theta(1-p)$ and $1-u$, respectively. At the information set V_L, the victim's posterior belief is $r^* = 2\theta/(d+2\theta)$ on the left node and $1- r^*$ on the right node, and it offers $s = d^2/2c$ with the probability $w = \theta/2d$, and $s = (d^2-2\theta d)/2c$ with the probability $1-w$. The polluter accepts this offer only when its payoff from the acceptance is greater than its payoff from rejecting the offer, that is, $s \geq d^2/2c$ for the low cost type and $s \geq (d^2-2\theta d)/2c$ for the high cost type, and otherwise it rejects the offer, implying that an international agreement fails in the latter case. The other possible equilibrium is a pooling equilibrium where both the

[9] This is explained more formally in the appendix. This low cost type polluter's payoff is obtained as α minus the area (a+c+h), which in turn is the area (b+f+g) minus the area (a+b+c+f+g+h) in Figure 1.

[10] A similar incentive problem is discussed by Huber and Wirl (1996) and Kerschbamer and Maderner (2001). As in Huber and Wirl (1996), the past abatement levels do not necessarily reveal the true damage cost of the polluter here.

low and high cost types of the polluter choose e_L^N as their non-cooperative abatement level. This equilibrium realizes if $p \geq 2\theta/(d+2\theta) = r^*$. In this pooling equilibrium, the victim does not update its posterior belief. The polluter's initial move is followed by the offer of $s = d^2/2c$ by the victim and this offer will be accepted. An international agreement on a rather small scale always materializes in this equilibrium.

The most interesting result obtained here is that there is a possibility that an international agreement is not reached successfully despite the fact that it represents a Pareto improving change.[11] In the hybrid equilibrium, an agreement fails with the probability $r^*(1\text{-}w) = \{\theta(2d\text{-}\theta)\}/\{d(d+2\theta)\}$, because the low cost type polluter rejects the offer of $s = (d^2\text{-}2\theta d)/2c$ from the victim. Let us define $q = r^*(1\text{-}w)$. Interestingly, the value of q does not depend on the victim's prior belief concerning the polluter's type. This is because, no matter what the victim's prior belief might be, the value of r has to equal $r^* = 2\theta/(d+2\theta)$ for a mixed strategy to become the equilibrium strategy for the victim, which in turn is required for the realization of the hybrid equilibrium. On the other hand, the victim's prior belief is critical in determining whether the hybrid equilibrium actually emerges. As long as p is sufficiently small, which means that the polluter is believed sufficiently likely to be the high cost type, we have a non-zero probability that a mutually beneficial international agreement is rejected by the polluter.

Furthermore, we can easily derive $\partial r^*/\partial d = \text{-}2\theta/(d+2\theta)^2 < 0$, which implies that, the more concerned the victim is about its own environmental damages, the less likely we have the hybrid equilibrium given a certain *ex ante* probability distribution over the types of the polluter. We can also obtain $\partial q/\partial d = 2\theta\{d(\theta\text{-}d)+\theta^2\}/\{d(d+2\theta)\}^2$, where q is the probability that an international agreement fails in the hybrid equilibrium. Then, a simple calculation shows that $\partial q/\partial d < 0$ always holds for $d \geq 2\theta$. This result implies that the likelihood of an eventual disagreement goes down with the increase in d. Both $\partial r^*/\partial d < 0$, and $\partial q/\partial d < 0$ indicate that an international agreement is more likely to be reached if the victim cares about its own environmental damages more significantly. These results are somewhat intuitive in that, the more important this environmental issue is to the victim, the more strongly it would seek an international agreement even if it might allow the high cost type polluter to disguise as the low cost type.

On the other hand, we can derive $\partial r^*/\partial\theta = 2d/(d+2\theta)^2 > 0$. This implies that, the greater the difference between the two polluter's types is, the more likely the hybrid equilibrium realizes, although whether we have the hybrid equilibrium or the pooling

[11] Our setting is an example of a "gap case" since the total welfare gain from an agreement is always strictly greater than the cost of implementing it, irrespective of the polluter's type (Muthoo 1999). Hence, if there are infinite opportunities of making proposals instead of just once as in our model, the two parties can always reach a mutually beneficial agreement in some finite time. However, the delay in reaching an agreement still represents an overall efficiency loss.

equilibrium also depends on the actual value of p. Moreover, we can derive $\partial q/\partial\theta = 2d\{d^2-\theta(d+\theta)\}/\{d(d+2\theta)\}^2$. Then, it follows that $\partial q/\partial\theta > 0$ for $d \geq 2\theta$. Hence, the likelihood of the actual failure of the international agreement in the hybrid equilibrium goes up with the increase in θ. Both $\partial r^*/\partial\theta > 0$ and $\partial q/\partial\theta > 0$ indicate that the two countries have more difficulty in reaching an agreement when the difference between the two types of the polluter is relatively large. In such a case, the high cost type polluter finds it more difficult to successfully disguise itself as the low cost type.

Finally, we assumed above that the polluter needs to commit to its initially announced non-cooperative abatement level in the sense that it has to implement this level of abatement when an agreement eventually fails. If the costs of revoking its previous announcement, such losing a reputation as a negotiator, are relatively insignificant, the polluter could renege on its previous announcement. There may be no other significant relations in which the polluter is engaged currently or in the foreseeable future. If such an act is completely costless, we only observe the pooling equilibrium where the polluter always chooses e_L^N at the node P_H^0. The high cost type polluter will never do worse by claiming e_L^N than by acting honestly because it is guaranteed the payoff of β even by initially choosing e_L^N in this case. Therefore, the belief of the victim at the information set V_L simply coincides with its prior belief. A simple calculation shows that, if $p \geq (2\theta d-\theta^2)/(d^2+2\theta d-\theta^2)$, the victim offers $s = d^2/2c$, and if $p < (2\theta d-\theta^2)/(d^2+2\theta d-\theta^2)$, it offers $s = (d-\theta)^2/2c$. Although this outcome is qualitatively different from the one above, there is still a possibility that an international agreement fails when $p < (2\theta d-\theta^2)/(d^2+2\theta d-\theta^2)$ because the low cost type polluter surely rejects the offer of $s = (d-\theta)^2/2c$.

4. Conclusion

The stalemate in addressing an international environmental issue can be explained partly by the incentive conflict arisen from asymmetric information on the environmental preference of a polluter. Without the information on its damage cost, a victim or any international agency cannot judge exactly what would be the internationally optimal level of abatement and the appropriate amount of side payment. In this study, we examined a signaling game between a polluter country and a victim country over an agreement to mitigate unidirectional transboudary pollution. In our simple analytical setting, we demonstrated that the existence of asymmetric information can prohibit the realization of a Pareto-superior international agreement under certain circumstances. Failure of an agreement occurs when the uncertainty over the polluter's damage cost is sufficiently significant compared to the size of the victim's damage cost.

Figures

Figure 1. Marginal Cost Curves and Different Abatement Levels

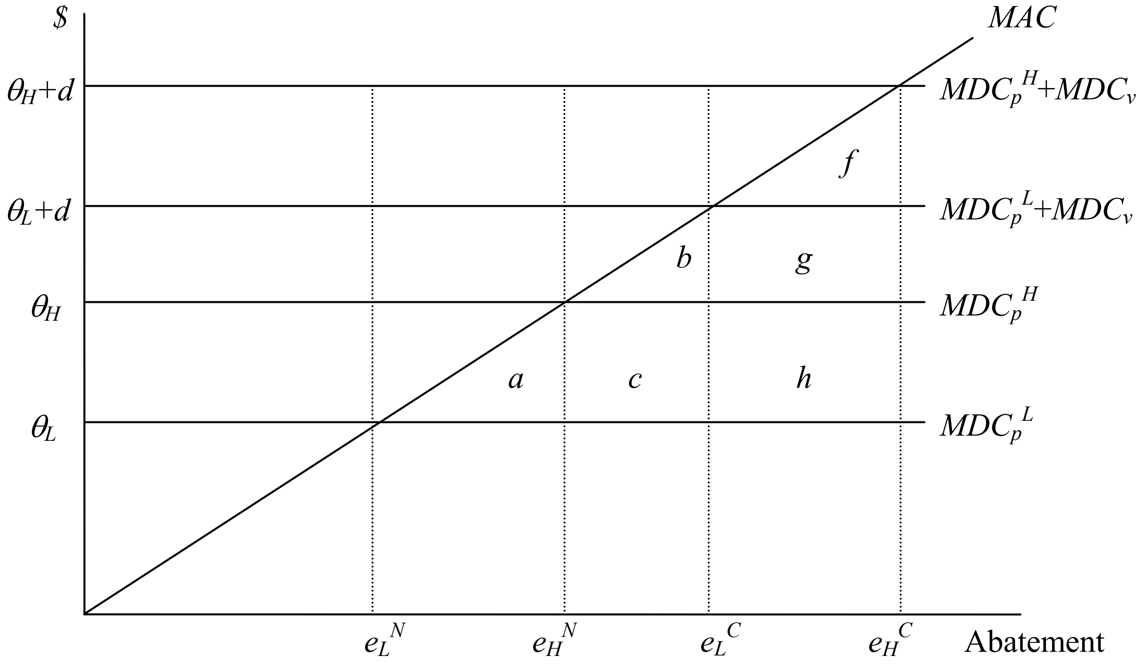
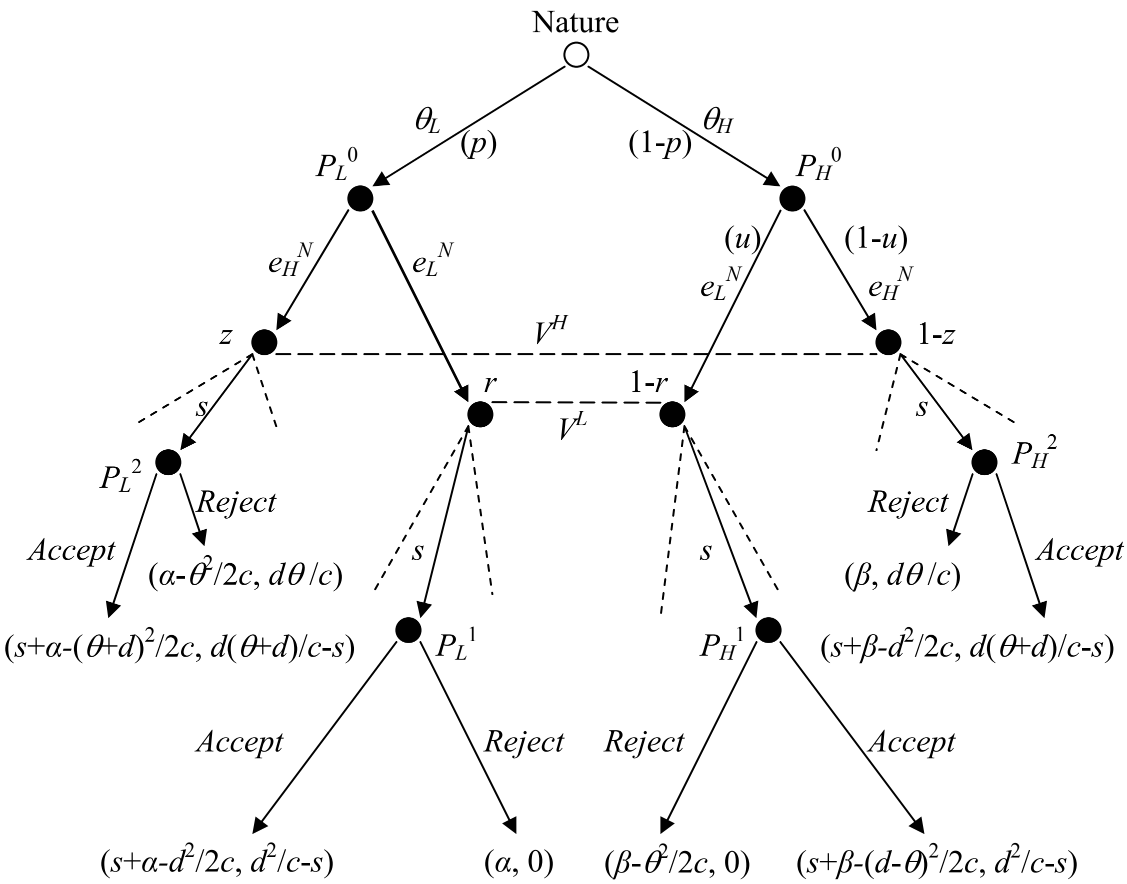


Figure 2. Game Tree



Appendix: Derivation of Perfect Bayesian Equilibria

As mentioned above, the low cost type polluter would never choose e_H^N at the node P_L^0 in Figure 2. It can secure the payoff of α by choosing e_L^N. In order for the low cost type polluter to have a greater payoff than α following its choice of e_H at the node P_L^0, the amount of the side payment needs to be more than $(\theta+d)^2/2c$ because it will be required to abate up to e_H^C as the cooperative abatement level. However, such a significant amount of side payment would result in a strictly negative payoff for the victim, thus annihilating the incentive for the low cost type polluter to imitate the high cost type. When the polluter chooses e_H, the victim is certain that it is the high cost type and offers $s = d^2/2c$, which will be accepted by the high cost type polluter at node P_L^2.

Basically, we can solve this game backward. The action of the polluter after either P_L^1 or P_H^1 in Figure 2 is straightforward. Each type of the polluter accepts a side payment from the victim and engages in an agreement only if its payoff from the acceptance is greater than its payoff from the rejection. In particular, this implies that the low cost type polluter ought to accept s if $s+\alpha-d^2/2c \geq \alpha$, that is, $s \geq d^2/2c$, and reject s otherwise at P_L^1. The high cost type polluter would rather accept s if $s+\beta-(d-\theta)^2/2c \geq \beta-\theta^2/2c$, which can be transformed to $s \geq (d^2-2\theta d)/2c$, and reject s otherwise at P_H^1.

Given these strategies of the two types of the polluter at these terminal nodes following e_L in the initial move and its belief over the types of the polluter, the victim determines the amount of side payment. The belief is characterized by the value of r, and the objective of the victim is to maximize its expected payoff. Let Pr(s) be the probability that the offer of s is accepted by the polluter. Then, the victim's problem is expressed as

$$\underset{s}{Max}\left(\frac{d^2}{c}-s\right)\Pr(s)\,. \tag{A1}$$

According to the polluter's response toward s at its last nodes, there are three possible values for Pr(s); Pr(s) = 1 when $s \geq d^2/2c$, Pr(s) = 1-r when $d^2/2c > s \geq (d^2-2\theta d)/2c$, and Pr($s$) = 0 when $s < (d^2-2\theta d)/2c$.

In order for the victim to employ a mixed strategy, the expected payoff from offering $s = d^2/2c$ must be equal to the expected payoff from offering $s = (d^2-2\theta d)/2c$. Thus, a mixed strategy is employed by the victim only when

$$(1-r)\left(\frac{d^2}{c}-\frac{d^2-2\theta d}{2c}\right)=\frac{d^2}{c}-\frac{d^2}{2c}\,. \tag{A2}$$

By solving (A2) for r, we obtain $r = 2\theta/(d+2\theta)$. This particular value of r turns out to be an important threshold and we have denoted it by r^* above. If the victim believes that there is more chance of the polluter's being the low cost type than r^*, it offers $s = d^2/2c$. On the contrary, when it believes that the polluter is less likely to be the low cost type than r^*, the victim offers $s = (d^2\text{-}2\theta d)/2c$. Then, only when $r = r^* = 2\theta/(d+2\theta)$, the victim employs a mixed strategy. Let us suppose that, as its mixed strategy, the victim chooses $s = d^2/2c$ with the probability w ($0 < w < 1$) and $s = (d^2\text{-}2\theta d)/2c$ with the probability $1\text{-}w$, respectively.

Now, we consider the action taken by the high cost type polluter at the node P_H^0. When it chooses e_H^N, the international agreement aimed at e_H^C will be implemented with the side payment which makes the high cost type polluter just as well off as at its truthful non-cooperative situation because the victim is certain that no low cost type polluter had chosen e_H^N at the node P_H^0, as we have seen above. Consequently, the high cost type polluter nets β by choosing e_H^N. Then, the expected payoff from choosing e_L^N must also be β for the high cost type polluter to randomize at P_H^0. In such a hybrid equilibrium, therefore, the following equation has to be satisfied:

$$w\left(\frac{d^2}{2c}+\beta-\frac{(d-\theta)^2}{2c}\right)+(1-w)\left(\frac{d^2-2\theta d}{2c}+\beta-\frac{(d-\theta)^2}{2c}\right)=\beta\,. \qquad \text{(A3)}$$

Solving (A3) for w, we obtain $w = \theta/2d$ (note that, because we assumed $d \geq 2\theta$, it is always the case that $0 < w = \theta/2d < 1$). Hence, for a mixed strategy to be the equilibrium strategy for the high cost type polluter, we need $w = \theta/2d$ in the victim's mixed strategy.

Finally, we must specify the belief of the victim when the information set V_L is reached. This posterior belief has to be determined by the Bayes' rule, given the victim's prior belief and the equilibrium strategy of the polluter. The probability with which the high cost type polluter chooses e_L^N at the node P_H^0 is u ($0 < u < 1$) as in Figure 2. As we have seen above, in order for the victim to employ its mixed strategy, we must have $r = 2\theta/(d+2\theta)$. Hence, by the Bayes' rule, the following equation must be satisfied:

$$\frac{2\theta}{d+2\theta}=\frac{p}{p+(1-p)u}\,. \qquad \text{(A4)}$$

Solving (A4) for u, we obtain $u = dp/2\theta(1\text{-}p)$. While the constraint $0 < u$ can be trivially satisfied, the constraint $u < 1$ provides a condition for obtaining the hybrid equilibrium. That is, we have the hybrid equilibrium only if $u = dp/2\theta(1\text{-}p) < 1$, which yields the condition upon p as $p < 2\theta/(d+2\theta)$. On the other hand, if $p \geq 2\theta/(d+2\theta)$, we have the pooling equilibrium where both the low cost and high cost types of the polluter choose e_L^N at P_L^0 and P_H^0, respectively.

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