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The value of information and the design of a climate contract under asymmetric information both before and after the contract is signed. *

by

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Abstract

The starting point of this paper is that a group of countries cooperate to reduce global emissions of CO_2. In order to reduce the cost of achieving a target for global emissions reduction, they offer a non-cooperating country a financial transfer for implementing abatement policies. The non-cooperating country has access to private information both before and after the contract is signed. We analyze the design of an abatement contract, and evaluate under what circumstances and at what time it is valuable for the cooperating countries to acquire more information about the non-cooperating country's abatement cost, although this is costly.

Key words: climate policy, incentive contracts, asymmetric information, joint implementation

1. Introduction

Emissions of greenhouse gases is a global problem that demands international agreement to be solved. By ratifying the United Nations Framework Convention on Climate Change (FCCC) more than 140 countries have expressed their willingness to take some kind of action. However, as of yet the FCCC does not include any legally binding commitments for emissions reduction.

It is the total amount of greenhouse gases in the atmosphere and not the geographical location of emissions that determines global warming. A cost-effective policy to mitigate emissions implies that marginal abatement cost should be equalized across all countries. However, it seems unlikely that all countries will participate in an international climate agreement due to free rider incentives. If many countries cooperate to reduce emissions, any individual country could be better off if the other countries cooperate, while the country does not take part in the agreement and pursues its own interest. In spite of free rider incentives we will in this paper assume that a group of countries have a self interest in avoiding deviation. (See Hoel (1994) and Barrett (1994) for a discussion of the existence of a stable coalition in spite of free rider incentives). These countries, referred to as the cooperating countries, are assumed to set a target for global CO_2-abatement in a future year. They introduce harmonized domestic CO_2 taxes or tradable emission permits to ensure cost-effectiveness within the cooperating countries. However, the cost of reaching the global target could be reduced if the cooperating countries could, through side payments, induce non-cooperating countries with lower abatement costs to reduce their emissions.

Several studies have pointed out the differences in CO_2-abatement costs across countries, and hence the scope for cost savings by a cost-effective distribution of abatement. See UNEP (1994) for a comparison of abatement costs in some developing countries and Kram (1993) for a comparison of abatement costs in selected OECD countries. Burniaux et al. (1992) have analyzed the cost saving potential of a cost-effective distribution of abatement. They consider a stabilization scenario in which the OECD countries stabilize their emissions by 2010 at 80 per cent of their 1990 levels and non-OECD countries stabilize their emissions at a level 50 per cent higher than their 1990 levels. They find that the global abatement cost of this stabilization scenario could be cut in half by cost-effective abatement.

The FCCC states that developed country Parties and countries that are undergoing the process of transition to market economy “may implement policies and measures jointly with other Parties in contributing to the achievement of the objective of the Convention” (article 4.2 (a)). This option is usually referred to as Joint Implementation (JI) or Activities Implemented Jointly (AIJ). JI is one way of reducing the global cost of achieving a cut in global emissions of greenhouse gases through international cooperation. The idea of JI is to reduce the total cost of a given reduction in the emissions of greenhouse gases by separating the commitment of each country Party from the implementation of measures. For a discussion of the merits and demerits of JI see Hanisch (1991), Barrett (1993a) and (1993b), Jones (1993), Bohm (1994), Mintzer (1994) and Hagem (1996). The term JI is usually used on investment in specific abatement projects. The investor finances specific JI projects and receives abatement credits for the abatement achieved through the projects. In this paper we will consider a regime where a non-cooperating country can choose which projects to implement in order to achieve a certain reduction in national emissions. The cooperating countries pay the non-cooperating country for the abatement when the reduction in emissions is observed.

Hoel (1994) discusses the option of inducing non-cooperating countries to implement national climate policies that affect the consumption and/or production of fossil fuels in these countries. This is achieved through financial transfers that make each country equally well off with the transfer and the climate policy as it would be without the transfer and the policy. In Hoel (1994) it is assumed that the cooperating countries have complete information about the non-cooperating countries’ cost of the climate policy. In this paper we analyze the cooperating countries' policy toward a non-cooperating country in a situation where relevant information about the non-cooperating country’s abatement cost is costly to obtain for the cooperating countries. The optimal design of a contract offered to a non-cooperating country under asymmetric information is analyzed. Furthermore, the value of additional but costly information for the cooperating countries is discussed. These questions will be analyzed within a principal-agent framework. The principal acts on behalf of the cooperating countries and the agent acts on behalf of the non-cooperating country. The principal acts as a Stackelberg leader that offers an abatement contract to the agent. For a survey of literature on regulation under asymmetric information see Caillaud et al. (1988) or Baron (1989).

We will assume that the agent gets access to private information at two different dates. The agent has private information at the time of entering into the contract. Furthermore, since the contract specifies an abatement level to be achieved some years ahead, we assume there are several factors that have an influence on the cost that is not available information at the time of entering into a contract, for neither the agent nor the principal. We will assume that the agent learns more about the non-cooperating country's abatement cost when different abatement projects have been implemented.

An example of this kind of contract could be a non-cooperating country that reduces the emission of CO_2 by substituting some of the national consumption of coal by gas for heat supply.[1] A conversion from coal to gas fired heat plants (boilers) would decrease the emissions of CO_2 per unit use of energy since the carbon content of gas is about 57 per cent of the carbon content of coal per energy unit. The cost of this investment will *inter alia* depend on the expected lifetime of the coal based boilers in use. If the existing technology is old and has to be replaced by new investment anyway, the cost of

[1] A coal-to-gas conversion pilot project, partly financed through a grant from The Global Environmental Facility (GEF) and the Government of Norway, is about to be implemented in Poland. (GEF is managed by the World Bank, the UNDP and UNEP). The grant partly covers the cost of a replacement of coal fired boilers with condensing gas fired boilers for heat supply and a replacement of coal fired boilers with a cogeneration unit based on gas supplying heat and electricity. See Selrod and Sørensen (1994) for a description of the project.

replacement would be less than if the existing technology had a long expected lifetime. Information about the condition of the existing technology is likely to be private information to the authorities in the non-cooperating country when the contract is signed. The exact cost of a conversion from coal-to-gas project depends on the impact on the demand for energy. The impact on the demand for energy depends on the price difference between coal and gas and the price elasticity. The exact impact on the demand for energy and hence the impact on emissions is not known to any of the parties at the time of signing the contract. The agent can, however, observe the impact on the energy demand of each of the projects and hence learn more about the cost of achieving a certain abatement target. Even though this information is not observed by the principal, we will show that it is optimal for the principal to allow for some flexibility in the contract. That is, the contract should specify different options for abatement levels, where the agent can choose the abatement level when the relevant information about the abatement cost is observed.

Cost-effective distribution of abatement implies that the marginal abatement cost should be equal in the cooperating and non-cooperating country. The principal's benefit of abatement carried out in the non-cooperating country is equal to the corresponding reduction in the cooperating countries' abatement cost. A cost-effective distribution of abatement in the case of asymmetric information *can* be achieved by giving the agent a monetary reward as a function of abatement, where the reward function is identical to the principal's benefit function of abatement carried out by the non-cooperating country. The agent would then choose an abatement level that implied that the marginal abatement cost in the non-cooperating country would equalize the principal's marginal benefit of abatement. This result was noted by Loeb and Magat (1979) for the case where the agent produced a quantity of a pure public good. Caillaud *et. al* (1988) point out that this mechanism corresponds to a *Groves scheme*. It was discovered by Groves (1973) and Clarke (1971) that any efficient provision of public goods can be implemented as long as budget balance is not required. In the problem discussed in this paper, financial transfer from the principal to the agent represents a loss to the principal. It is shown in the literature on asymmetric information that when there is a cost of transferring money, the efficient output is not necessarily the preferred output by the principal. The optimal solution trades off financial losses against efficiency losses.

Baron and Myerson (1982) show the derivation of an optimal regulation of a monopolist with unknown marginal cost when there is a cost of transferring money to the firm. In this paper we will use a “two-types of agents” version of that model. The model is expanded with a cost parameter that is unknown at the time of signing the contract but observable for the agent at a later time. The agent will hence have access to private information both before and after the contract is signed. We assume that the there is no correlation between the information received at the different dates.[2] We show that the optimal contract offered to the agent specifies financial transfers and abatement levels depending of the agent's announcement of its private information at the different dates when the information is acquired. Sequential communication of private information is studied in a paper by Christensen and Feltham (1994). They study a contract situation where a principal hires an agent to perform a task. The outcome is a function of the agent’s effort, which is unobservable to the principal, and a random state of nature. The agent is risk averse and effort averse. The agent has no private information when the contract is signed, but receives two private signals, at different dates, before he implements his effort choice to perform the task. They show that the principal weakly prefers that the agent reports each signal at the date it is observed, compared to a simultaneous report of both signals when the second signal is observed. In this paper we assume that the agent is risk neutral. If the agent is risk neutral and has no private information at the time when the contract is signed, private information after the contract is signed represents no cost for the principal if the agent can commit to not quit the

[2] Laffont and Tirole (1993, ch.1.8) study a contractible investment model with a similar timing of private information as in this paper. In their model, the agent has private information about an efficiency parameter of its investment before entering into a contract. The agent privately observes the realization of an operating cost parameter after the contract is signed and privately observes its own effort to perform the task specified in the contract. The principal and the agent contract on investment and the cost of performing the task. They show how the investment level must be corrected to contribute to rent extraction when there is a *correlation* between the efficiency parameter of investment and the operating cost parameter.

relationship.[3] However, we will show that if the agent has some private information before entering into the contract, additional private information at a later date will be costly for the principal even if the agent is risk neutral. The principal's cost of the contract will be reduced if the agent announces its private information at the different points of time when the information is observed compared a simultaneous announcement after both types of information have been observed.

Since the climate contract considered in this paper is a contract between countries, we assume that it is not possible for the principal to enforce the agent to fulfill the contract if the agent finds it more beneficial to breach the contract. The only instrument for inducing the agent to fulfill the target is the monetary transfer specified in the contract. A situation where the agent can find it beneficial to breach the contract in the case of bad realizations of the cost parameter corresponds to a situation in which the agent is unable to fulfill the contract for bad realizations of the cost parameter due to limited liability. Sappington (1983) shows that a limited liability constraint induces the principal to design a contract that distorts output from the first-best level even though the firm had no private information at the time the contract was signed.

We assume that the principal will never breach the contract or demand to renegotiate the contract. The justification for this assumption is that the principal might want to keep a good reputation in case it will offer abatement contracts to other countries (or the same country) in the future.

Before designing the contract, the principal decides how much costly information she should try to obtain. The principal has two options for what time she could acquire information. Information about the non-cooperating country’s expected abatement cost

[3] If the agent is risk neutral, can commit not to quit the relationship and all information is symmetric when the contract is signed, the principal designs a contract which induces the agent to report its private information obtained after the contract is signed truthfully and leaves the agent with zero expected rent. The case of a risk neutral agent, symmetric information before the contract is signed and private information after has, among others, been discussed in Rey and Tirole (1986) and Baron (1989).

can be obtained before the contract is offered. Furthermore, the principal can design a contract that will give her access to the same information as the agent obtains during the contract period. This could, for instance, be achieved if the principal monitored or took some direct part in the implementation of abatement projects. Both options for acquiring more information are assumed to be costly for the principal.

In the next section we present the model and the optimal design of a contract in the absence of asymmetric information. In the third and fourth section we derive the design of abatement contracts when the agent has access to private information. Furthermore, we analyze the value for the principal of acquiring more information about the cost function before the contract is offered to the agent, and the value of designing a contract where the principal observes the same information as the agent after the contract is signed. Concluding remarks are given in the last section.

2. The model

2.1. Preferences and technology

The principal acts on behalf of the cooperating countries and seeks to minimize the expect total cost of achieving a certain target for global abatement within a future year.

It is assumed that the principal has complete information about the cooperating countries' abatement costs. However, she has incomplete information about the non-cooperating country’s expected abatement cost at the time of entering into the contract. Furthermore, the principal knows that the non-cooperating country’s abatement cost is a function of a stochastic variable, where the realized value is unknown when the contract is signed, but will be observed by the agent in a future year previous to the target year. The principal is risk neutral. The cost of reaching the abatement target is the sum of the abatement costs within the cooperating countries and the financial transfer the principal has to give to the agent, in order to induce the country to abate, plus the possible costs of acquiring information. *ATC* is the principal’s abatement cost of achieving the abatement target less of the cost of acquiring information.

ATC is given by

$$ATC(R,r) = D(R-r) + S \qquad D^{/}(\cdot) > 0,\ D^{//}(\cdot) > 0 \qquad (1)$$

R is the global abatement target, r is the abatement carried out by the agent, $D(\cdot)$, is the cooperating countries' abatement cost function, and S is the financial transfer to the agent.

The agent acts on behalf of the non-cooperating country. The agent is risk neutral and profit maximizing. The agent's profit (P) of the abatement contract is given by

$$\Pi(r,\mathrm{b},\mathrm{q}) = S - C(r,\mathrm{b},\mathrm{q}) \qquad (2)$$

where $C(\cdot)$ is the non-cooperating country's abatement cost function.

q and b are independent parameters. We have the following assumptions about the cost function;

$$C_r^{/}(\cdot) > 0, C_{rr}^{//}(\cdot) > 0, C_{\mathrm{b}}^{/}(\cdot) > 0,\ \ C_{\mathrm{q}}^{/}(\cdot) > 0,\ \ C_{r\mathrm{b}}^{//}(\cdot) > 0 \ \textit{and}\ \ C_{r\mathrm{q}}^{//}(\cdot) > 0 \qquad (3)$$

The marginal abatement cost is positive and increasing in r, b and q.

2.2. Information

β is known to the agent at the time of entering into the contract. θ is observed by the agent after the contract is signed. We assume that it is possible for the principal to acquire information about β before the contract is offered to the agent. Information about β could be acquired through studies of the condition of the existing technology used in the agent country, abatement cost functions, etc. Gathering information about β is, however, costly for the principal. The principal could also design a contract where the agent's observation of θ also was available to the principal. This could be the case if, for instance, the agent had to let the principal monitor the abatement projects. This monitoring process is assumed to be costly for the principal.

2.3. Time-line

0	1	2	3
The principal can acquire information about b.	The principal offers the agent a contract. The agent knows b.	The random variable q is observed by the agent. The Principal can acquire information about q.	The abatement is observed. The agent is paid according to the contract.

We will restrict the analysis to the case where b and q belong to the two-point supports $\{b^1, b^2\}$and $\{q_1, q_2\}$, where $b^1 < b^2$ and $q_1 < q_2$. If b is b^1, we will refer to the non-cooperating country as a b^1-type, and refer to non-cooperating country as b^2-type if b is b^2. The agent knows at time t=1 whether the non-cooperating country is a b^1-type or a b^2- type. We assume that $C(r,b^1,q_2) < C(r,b^2,q_1)$ and that $C'_r(r,b^1,q_2) < C'_r(r,b^2,q_1)$, which means that the b^1-type has a lower total and marginal abatement cost than the b^2-type for both outcomes of q. b is hence more important for total and marginal abatement cost than q.[4] We will throughout the paper assume that the principal wants the agent to implement the climate policy even for bad outcomes of the cost parameters.

We will first consider the design of an abatement contract in the case where the principal does not acquire costly information about b or seeks to monitor the agent's observations of q. Applying the Revelation Principle established in Dasgupta et al. (1979) and Myerson (1979), we can restrict our attention to contracts for which the agent reports the private information truthfully. We seek to find the truthful direct mechanism for which the agent reports the value of b truthfully at time t=1 and the value of q truthfully

[4] This assumption ensures that there is no ambiguity regarding which of the two types' incentive compatibility constraints and individual rationality constraints (defined in section 2.4 and 2.5) that will be binding in the optimal contract.

at time t=2. We assume that if the agent is indifferent between lying and telling the truth, he tells the truth.

Let b and d be the agent's announcement of b and q respectively. $b \in \{b^1, b^2\}$ where b^1 = b^1 and $b^2 = b^2$ and $d \in \{d_1, d_2\}$ where $d_1 = q_1$ and $d_2 = q_2$.

The agent does not know the outcome of θ at time t=1. The principal designs a two-contract menu. One contract is designed for the β^1-type and one is designed for the β^2-type. The agent observes the two contracts and announces that the country is a β^1-type or a β^2-type and gets the contracts designed for the type he announces. Both contracts specify two options for a combination of abatement levels (r) and financial transfers (S). The abatement levels in each of the contracts are functions of the announcement of θ when observed by the agent at time t=2. The abatement levels specified in the contracts are hence functions of the announcement of b at time t=1 and q at time t=2. The financial transfers are functions of the abatement levels. We can therefore write the agent's profit function, given by (2), as $\Pi(r(b,d), \mathrm{b}, \mathrm{q}) = S(r(b,d)) - C(r(b,d), \mathrm{b}, \mathrm{q})$.

2.4. Incentive constraints

We have two incentive constraints for truth-telling about b at time t=1:

$$IC1^i: \mathrm{EP}\,(r(b^i,d(b^i, \mathrm{b}^i,\mathrm{q})),\mathrm{b}^i,\mathrm{q}) \geq \mathrm{EP}\,(r(b^k,d(b^k, \mathrm{b}^i,\mathrm{q})),\mathrm{b}^i,\mathrm{q}) \qquad i=1,2;\ k=1,2;\ k\neq i \tag{4}$$

where

$$d(b, \mathrm{b}, \mathrm{q}) = \underset{d \in d_1, d_2}{\arg\max.}\ \Pi\,(r(b,d), \mathrm{b}, \mathrm{q}) \tag{5}$$

We have four incentive constraints for truth-telling about q at time t=2;

$$IC2^i_j: \mathrm{P}\,(r(b^i,d_j),\mathrm{b}^i,\mathrm{q}_j) \geq \mathrm{P}\,(r(b^i,d_h),\mathrm{b}^i,\mathrm{q}_j) \qquad i=1,2;\ j=1,2;\ h=1,2 \text{ and } j\neq h \tag{6}$$

(4) states that it is incentive compatible for the agent to report β truthfully at time t=1, given the best response function $\delta(\cdot)$ at time t=2 as defined by (5). (6) states that the best response at time t=2, given truthful reporting of β at time t=1, is to report θ truthfully.

Let $r^i{}_j$ and $S^i{}_j$ be the abatement level and financial transfer specified in the contract given to the agent if he reports $b = \beta^i$ at time t=1 and $d = \theta_j$ at time t=2, and let $C^i{}_j(r) \equiv C(r, \beta^i, \theta_j)$. Furthermore, let the financial transfer and abatement pairs $\{S^i{}_1, r^i{}_1\}$ and $\{S^i{}_2, r^i{}_2\}$ be the two options offered to the agent if he announces $b = \beta^i$ at time t=1.

It follows from (2) that the constraints given by (6) for the β^1-type amount to

$$C^1{}_1(r^1{}_1) - C^1{}_1(r^1{}_2) \le \delta^1 \le C^1{}_2(r^1{}_1) - C^1{}_2(r^1{}_2), \text{ where } \delta^1 \equiv S^1{}_1 - S^1{}_2 \qquad (7)$$

and the constraints given by (6) for the β^2-type amount to

$$C^2{}_1(r^2{}_1) - C^2{}_1(r^2{}_2) \le \delta^2 \le C^2{}_2(r^2{}_1) - C^2{}_2(r^2{}_2), \text{ where } \delta^2 \equiv S^2{}_1 - S^2{}_2 \qquad (8)$$

(7) and (8) set restrictions on the differences in financial transfer as a function of the abatement demanded in each of the contracts. A condition for these constraints to be satisfied is that $r^i{}_1 \ge r^i{}_2$ since $C^{//}_{r\theta}(\cdot) > 0$. We will in the following assume that $r^i{}_1 \ge r^i{}_2$ in the two-contract menu offered to the agent.

2.5. The principal's expected cost and agent's individual rationality constraints

The principal's expected cost of the two-contract menu is a function of the abatement levels and financial transfer specified in the contract and the probability distributions for β and θ. Let v be the principal's subjective probability that the non-cooperating country's abatement cost parameter is β^1. Let p be the agent's and principal's common belief about the probability for θ to turn out to be θ_1 at time t=2.

The principal’s expected cost of reaching the global abatement target is given by

$$
\begin{aligned}
E[ATC] = \ & v \begin{bmatrix} p(D(R - r_1^1) + S_1^1) \\ +(1-p)(D(R - r_2^1) + S_2^1) \end{bmatrix} \\
& +(1-v) \begin{bmatrix} p(D(R - r_1^2) + S_1^2) \\ +(1-p)(D(R - r_2^2) + S_2^2) \end{bmatrix}
\end{aligned}
\tag{9}
$$

The principal’s optimization problem is to minimize (9) subject to the incentive compatible constraints (4) and (6) and the individual rationality constraints which are given by

$IR^i : EP(r(b^i,q)) \geq 0 \quad i=1,2$ (10)

and

$IR^i_j : P(b^i,q_j) \geq -g \quad i = 1,2; \ j=1,2 \qquad g \geq 0$ (11)

(10) states that the agent’s expected profit of accepting the contract should be higher or equal to the reservation utility, which is normalized to zero.

(11) states that the profit of both outcomes of q should be larger or equal to -g, where g is the cost of the climate policy implemented before q is observed. g can be regarded as sunk cost. (11) is an *ex post* participation constraint. The agent will breach the contract if (11) is not satisfied.

In the following we will consider two different situations. First we will consider the situation where the agent will have carried out several abatement projects before q is observed. This means that the sunk cost (g) is large when the agent observes q. This could be the situation if the non-cooperating country has to implement a range of different kinds of abatement projects to achieve a certain abatement level. The country therefore has to implement several different projects before θ is learned. We assume that γ is so large when θ is observed that the *ex post* participation constraint, given by (11), never will be binding in the optimal contract. We refer to this situation as a situation where the cost of breaching the contract, (which equals γ), is high. The optimal contract in this situation is derived in section 3.

In section 4 we will consider the situation where the agent observes θ when only a few projects have been implemented, that is, γ is low when θ is observed. This could be the situation if the agent is going to implement lots of very similar projects to achieve a certain target for abatement. The agent will therefore learn the outcome of θ after having implemented only a few of the projects. We assume that γ is so small when θ is observed that the *ex post* participation constraint, given by (11), will be binding in the optimal contract. We refer to this situation as situation where the cost of breaching the contract, (which equals γ) , is low.

To discuss the impact of asymmetric information and uncertainty, we first derive the solution for the case where the principal has complete information about β at the time t=1 and observes θ at time t=2.

2.6. Optimal contract under full information about β and observable θ at time t=2

The principal's optimization problem is to minimize (9) with respect to S^i_j and r^i_j subject to (10) and (11). Since the financial transfer is costly for the principal, the individual rationality constraints given by (10) are binding.

If β equals β^1 the solution to the cost minimization problem is found by minimizing (9) for v equal to 1 with respect to r^1_j and S^1_j, where the constraints IR^1 given by (10) are binding.

The solution to the minimization problem is given by

$$-\frac{dD}{dr_j^1} = \frac{dC_j^1}{dr_j^1} \qquad j = 1,2 \tag{12}$$

$$p(S_1^1) + (1-p)(S_2^1) = p\left[C_1^1(r_1^1)\right] + (1-p)\left[C_2^1(r_2^1)\right] \tag{13}$$

If b equals b^2 the solution to the cost minimization problem is found by minimizing (9) for *v* equal to 0 with respect to r^2_j and S^2_j, where the constraints IR^2 given by (10) are binding.

The solution to the minimization problem is given by

$$-\frac{dD}{dr_j^2} = \frac{dC_j^2}{dr_j^2} \qquad j = 1,2 \tag{14}$$

$$p(S_1^2) + (1-p)(S_2^2) = p(C_1^2(r_1^2)) + (1-p)(C_2^2(r_2^2)) \tag{15}$$

$\frac{dD}{dr_j^i}$ $(= -\frac{dD}{d(R-r_j^i)})$ expresses the cooperating countries' reduction in marginal abatement cost as a function of abatement carried out in the non-cooperating country. $-\frac{dD}{dr_j^i}$ is hence the principal's marginal benefit of abatement carried out in the non-cooperating country. We see from (12) and (14) that the contract is designed so that the principal's marginal benefit of abatement carried out in the non-cooperating country equals the non-cooperating country's marginal abatement cost for all outcomes of the cost function. The optimal contract is achieved for all combinations of S^i_1 and S^i_2 that satisfy IR^i. By choosing S^i_j equal to $C^i_j(r^i_j)$ the principal can always ensure that (11) is satisfied.

This is first-best solution for the distribution abatement. The abatement is distributed cost-effectively between the cooperating countries and the non-cooperating country for all outcomes of the cost function. Furthermore, it follows from (13) and (15) that the principal extracts all rent.

3. The optimal contract when the cost of breaching the contract is high

In this section we analyze the principal's optimal policy when the individual rationality constraints given by (11) are always satisfied if the constraints given by (10) are satisfied. We will first derive the optimal contract in the case of asymmetric information about b but observable q for both the principal and the agent at time t=2. This will be the case if the principal takes direct part in the implementation of the abatement projects and gets access to the same information as the agent at time t=2. Thereafter we derive the optimal contract in the case where b is known by both parties at time t=1, but the outcome of q is observed only by the agent. This will be the situation if the principal acquired information about b at time t=0, but did not observe the outcome of q at t=2. In section 3.3 we derive the optimal contract when b is unknown to the principal when the contract is signed and q will only be observed by the agent.

3.1. The optimal contract when the agent has private knowledge about b and q is observed by both parties

It follows from the fact that the agent's abatement cost function is increasing in b, that IR^1 given by (10) is satisfied if $IC1^1$ and IR^2, given by (4) and (10), are satisfied. We can hence ignore IR^1 in the optimization problem. The b^1-type's marginal abatement cost is lower than the b^2-type's marginal abatement cost for both outcomes of q. If IR^2 is satisfied, the agent will get a positive profit if the non-cooperating country is a b^1-type and the agent announces that it is a b^2-type. The agent has therefore an incentive to overstate the true cost parameter if the non-cooperating country is a b^1-type. The principal has to ensure that the contract design induces the agent to report b truthfully if b equals b^1. Since financial transfer is costly to the principal, the Individual Rationality constraint for the b^2-type, (IR^2), and the Incentive Compatibility constraint for the b^1-type, ($IC1^1$) are binding in the optimal contract. The principal's optimal two-contract menu is found by minimizing (9) with respect to r^i_j and S^i_j, subject to the binding constraints IR^2 given by (10) and $IC1^1$ given by (4). The agent has to announce q truthfully at time t=2 since the outcome of q is observed by the principal.

The solution to the problem is characterized by :

$$-\frac{dD}{dr_1^2} = \frac{dC_1^2}{dr_1^2} + \frac{v}{1-v}\left(\frac{dC_1^2}{dr_1^2} - \frac{dC_1^1}{dr_1^2}\right) \tag{16}$$

$$-\frac{dD}{dr_2^2} = \frac{dC_2^2}{dr_2^2} + \frac{v}{1-v}\left(\frac{dC_2^2}{dr_2^2} - \frac{dC_2^1}{dr_2^2}\right) \tag{17}$$

and r^1_1 and r^1_2 given by (12).

It follows from the binding constraints IR^2 and $IC1^1$ that the financial transfers specified in the contract give

$$E\Pi^2 = 0 \tag{18}$$

and

$$E\Pi^1 = p(C_1^2(r_1^2) - C_1^1(r_1^2)) + (1-p)(C_2^2(r_2^2) - C_2^1(r_2^2)) \geq 0 \tag{19}$$

We see from (19) that expected profit of accepting the contract is positive for the b^1-type. It follows from our assumptions about the non-cooperating country's abatement cost that the second term on the right hand side of (16) and (17) is positive. The principal's marginal benefit of abatement exceeds the marginal abatement cost in the optimal contract designed for the b^2-type. Asymmetric information causes too low abatement and no expected profit for the b^2-type and a positive expected profit and first-best abatement level for the b^1-type. The asymmetric information about b forces the principal to leave an expected profit, often referred to as an informational rent, to the b^1-type in order to induce the agent to tell the truth about b. The informational rent is increasing in the abatement demanded from the b^2-type. The reason for this is that the difference between the marginal abatement cost between the b^1-type and b^2-type is higher the higher abatement demanded ($C_{r\mathrm{b}}^{//} > 0$). The principal faces a trade of between leaving an expected profit to the b^1-type and low abatement demanded from b^2-type. To reduce the expected profit to the b^1-type the investor lowers the abatement level requested from the b^2-type.

3.2. The optimal contract in the case where β is known by both parties at time t=1, but the outcome of θ is observed only by the agent.

We have assumed that the principal can obtain information about b before the agent is offered the contract. At time t=0, before the principal acquires information about the non-cooperating country's expected abatement cost, she knows that there is a probability *v* that b equals b^1 and a probability 1-v that b equals b^2. When the principal has observed b, she designs a contract at time t=1 that minimizes the expected abatement cost given full information about b. At time t=0 the optimal contract design of this policy is found by minimizing (9) with respect to r^i_j and S^i_j, subject to the two individual rationality constraints given by (10) and the incentive compatibility constraints at time t=2 given by (7) and (8).

Given that δ^1 and δ^2 are chosen so that (7) and (8) are satisfied, the values have no impact on the expected profit left to the agent. The binding constraints are IR^1 and IR^2 given by (10). The solution to this problem is abatement levels given by (12) and (14) and combinations of S^i_1 and S^i_2 which satisfy (7), (8), (13) and (15). The two-contract menu induces the agent to reveal its private information about q truthfully at time t=2. The agent's profit will depend on the outcome of q, but the principal is able to extract the expected rent through the financial transfers specified in the contracts. The fact that q is not observed by the principal does not distort the contract away from first-best abatement levels if the agent has no private information when entering into the contract.

3.3. The optimal contract when β is unobserved by the principal and θ will only be observed by the agent.

The principal's optimal two-contract menu is found by minimizing (9) subject to the binding constraints $IC1^1$ and IR^2 and the four constraints given by (6). We see from (4), that $IC1^1$ is a function of d(b,b,q), as defined by (5). If $IC2^1$, given by (6) is satisfied, $IC1^1$ can be written as

$$IC1^1\text{: } EP\ (r(b^1,q),b^1,q) \geq EP\ (r(b^2,d(b^2, b^1,q)),b^1,q) \tag{20}$$

where $d(b^2, b^1, q)$ is given by (5).

The agent has two possible announcements for d, either d_1 or d_2. It follows from our cost function assumptions that given that (8) is satisfied and q is q_1, it is always more profitable to take the contract $\{S^2{}_1, r^2{}_1\}$ than $\{S^2{}_2, r^2{}_2\}$, given that the agent is b^1-type. This means that $d(b^2, b^1,q_1,) = d_1$. However, if $q = q_2$, the profit for the b^1-type of lying about q at time t=2 is higher than telling the truth given that the agent lied about b at time t=1. Inserting from the agent's profit function we see that $d(b^2, b^1,q_2,) = d_1$ satisfies (5) if

$$d^2 > C_2^1(r_1^2) - C_2^1(r_2^2) \tag{21}$$

Inserting from the lower bound of d^2 given by (8), we see that (21) is satisfied for all d^2 if

$$C_1^2(r_1^2) - C_1^2(r_2^2) > C_2^1(r_1^2) - C_2^1(r_2^2) \tag{22}$$

(22) is satisfied since we have assumed that $C'_r(r,b^1,q_2) < C'_r(r,b^2,q_1)$ and $r^2{}_1 \geq r^2{}_2$ in the optimal contract. This implies that $d(b^2, b^1,q_2) = d_1$.

The solution to the principal's optimization problem is found by minimizing (9) with respect to r^i_j and S^i_j subject to the binding constraints. The informational rent left to the b^1-type is increasing in d^2. d^2 is hence in the optimal contract set equal to the lower bound of (8). The binding constraints in the optimal contract are therefore IR^2, $IC1^1$ where $d(b^2, b^1, q) = d_1$ and $IC2^2_1$.

The solution to the optimal contract design problem is characterized by:

$$-\frac{dD}{dr_1^2} = \frac{dC_1^2}{dr_1^2} + \frac{v}{1-v}\left[\left(\frac{dC_1^2}{dr_1^2} - \frac{dC_1^1}{dr_1^2}\right) + \frac{1-p}{p}\left(\frac{dC_1^2}{dr_1^2} - \frac{dC_2^1}{dr_1^2}\right)\right] \tag{23}$$

$$-\frac{dD}{dr_2^2} = \frac{dC_2^2}{dr_2^2} + \frac{v}{1-v}\left[\left(\frac{dC_2^2}{dr_2^2} - \frac{dC_1^2}{dr_2^2}\right)\right] \tag{24}$$

and r^1_1 and r^1_2 given by (12)

From the binding constraints IR^2, $IC1^1$ and $IC2^2_1$ it follows that the financial transfers specified in the contract give

$$E\Pi^2 = 0 \tag{25}$$

$$\begin{aligned} E\Pi^1 &= +C_1^2(r_1^2) - C_2^1(r_1^2) \\ &\quad + p\left[C_2^1(r_1^2) - C_1^1(r_1^2)\right] + (1-p)\left[C_2^2(r_2^2) - C_1^2(r_2^2)\right] \geq 0 \end{aligned} \tag{26}$$

We see from (23) and (24) that r^2_1 and r^2_2 are lower than the first-best abatement levels given by (14). The agent will get a positive rent if the non-cooperating country is a b^1-type. It follows from the assumptions about the abatement cost function that both terms in the square-bracket in (23) are positive. When comparing the optimal contract in section 3.1, where q is observed by the principal, with the optimal contract above we see that r^2_1 and r^2_2, given by (23) and (24), differ from the optimal abatement given by (16) and (17). In the contract above, the b^1-type, if the agent announced that it was a b^2-type at time t=1, will find it optimal to choose the r^2_1 abatement level for both outcomes of

q at time t=2. An increase in r^2_1 will hence increase the expected profit of lying at time t=1 more in the contract designed above than in the contract designed in section 3.1. The optimal contract designed when q is unobserved by the principal will therefore specify a lower abatement level r^2_1 than the contract designed when the principal observes q at time t=2.

The r^2_2 abatement level has no direct effect on the informational rent in the contract above since the b^1-type will never find it optimal to choose the r^2_2 abatement level at time t=2, given that the agent lied about b at time t=1. However, an increase in r^2_2 will increase the financial transfer S^2_1 because of IR^2 and $IC1^2$. The level of r^2_2 thus has an indirect impact on the informational rent. Since S^2_1 is increasing in r^2_2, the expected rent of taking the contract designed for the b^2-type increases when r^2_2 increases. However, an increase in r^2_2 has less impact on the informational rent given to the b^1-type when q is unobserved by the principal, than when q is observed by the principal. The contract designed when q is unobserved by the principal will therefore specify a higher r^2_2 than the contract designed when the principal observes q at time t=2.

We have restricted the analysis to a "two-q-outcomes" model. However, if q was continuously distributed, it would always be optimal for the b^1-type to announce a lower value of q than the true value, given that the agent had lied about b at time t=1.

The possibility for *understating* q at t=2 increases the expected profit of lying about b at t=1. In order to reduce the cost of inducing truth-telling about b, the principal will induce the low values of abatement levels specified for the b^2-type to deviate less from the first-best level than the high values of abatement levels compared to the situation where q is observable.

As we showed in section 3.2, the fact that the outcome of q was observed only by the agent at time t=2, did not distort the contract away from first-best if b was observed by both parties at time t=1. However, the agent's private information after the contract is signed is costly to the principal *in combination* with private information before the contract is signed, even though the agent is risk neutral and the cost of breaching the contract is high.

We see from the optimal two-contract menu derived in this section that it is always profitable for the principal to design a contract where the b^1-type can choose the abatement level after the value of q has been observed. That is, r^1_1 differs from r^1_2 in the optimal contract. It is also profitable to offer a flexible contract to the b^2-type unless for the special case where the difference in the marginal abatement cost in the optimal contract for the two different outcomes of q is exactly offset by the difference in the marginal impact on the informational rent for $r^2_1 = r^2_2$.

It also follows from our model that it is always beneficial for the principal to design a two-contract menu where the agent has to choose among the two contracts at time t=1 instead of a single contract offered at time t=1 where b and q are announced simultaneously at time t=2. By forcing the agent to announce b at time t=1, and q at time t=2, the principal reduces the informational rent necessary to induce the b^1-type to reveal b and q truthfully. A single contract offered at time t=1 where the agent does not have to announce b before q is observed, would specify four different combinations of abatement levels and financial transfers $\{S,r\}$.[5] One combination designed for each of the four outcomes of $\{b,q\}$ the agent announces at time t=2. It follows from the fact that $C^1_1 < C^1_2$, that the combination of $\{S^1_2,r^1_2\}$ specified in the two-contract menu characterized by (12), (23)- (26) does not ensure truthtelling for the b^1-type when q equals q_2, and the agent announces the outcomes of $\{b,q\}$ at time t=2. A contract where the agent announces b and θ simultaneously at time t=2 will leave the agent with a higher expected profit, than when the agent had to announce b before q was known.

The uncertainty about q at time t=1, compared to a situation where q was private knowledge to the agent at time t=1, reduces the principal's cost for two reasons. First, the fact that q is uncertain for the agent at time t=1 implies that the principal can design a two-contract menu where the agent has to announce b before q is known and hence reduces the informational rent left to the b^1-type. Second, if the agent had known the true cost at time t=1, he would never accept the contract if the profit was less than the reservation utility. Hence, the principal would have to ensure that the profit for the $\{b^2,q_2\}$ outcome had to be at least as large as the agent's reservation utility, since we have assumed that the principal find it beneficial to contract with the agent for all outcomes of $\{b,q\}$. This constraint would increase the expected rent given to the agent. (The optimal contract in the case where there are restrictions on the profit for the high cost agent is analyzed in section 4).

The first-best contract would be achieved if both b and q were unknown to the agent when the contract was signed at time t=1. The binding individual rationality constraint in that case would require that the expected profit is non-negative, that is $v \cdot E\Pi^1 + (1-v) \cdot E\Pi^2 \geq 0$, while the constraint IR^2 given by (10) did not have to be satisfied.[6] The incentive compatibility constraint would not represent a cost to the principal when the agent maximizes expected profit and would never find it beneficial to breach the contract. If the agent has no private information when entering into the contract, the optimal contract would induce the agent to report its private information obtained after the contract is signed truthfully and leave the agent with zero expected rent.

3.4. The value of acquiring information

If b is known to the principal at time t=1, the fact that q is privately observed by the agent at time t=2 does not distort the contract away from first-best. The principal does

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[5] In order to ensure that the contract is incentive compatible, r must be non-decreasing in C, that is $r^1_1 \geq r^1_2 \geq r^2_1 \geq r^2_2$.

[6] We assume that g is so large that (11) is satisfied in the contract.

not gain anything from designing a contract where she will observe q if b is known to the principal at time t=1.

If the principal did not acquire information about b, it is valuable for the principal to observe θ because the agent's private observation of θ increases the informational rent for the β^1-type. The cost of monitoring θ will determine whether it is optimal for the principal to design a contract where θ is observed at time t=2.

The principal's abatement cost will always be higher when β is private information to the agent, than when β is common knowledge. The expected gain of acquiring information about β at time t=0 is positive if the expected abatement cost following from the first-best contract given by (12)-(15), plus the cost of acquiring information, is less than the expected abatement cost following from the optimal contract when β is private knowledge to the agent, characterized by (12) and (23) - (26).

4. The optimal contract when the cost of breaching the contract is low

We know from the optimal two-contract menus derived in section 3 that EP^2 was equal to 0. If q was not observed by the principal, the incentive compatibility constraints for truth-telling at time t=2, given by (8), implied that $P^2_2 < 0$. In this section we will analyze the optimal contract in a situation where the *ex post* participation constraint given by (11), will be binding. This means that the principal has to ensure that, when the agent observes the complete cost of abatement, the profit of fulfilling the contract is as least as large as the cost of the abatement projects already implemented (g). We will assume that g is small enough to ensure that IR^1 and IR^2 are satisfied if IR^2_2, $IC1^1$, $IC2^1$ and $IC2^2$ are satisfied.

4.1. The optimal contract when the agent has private information about b *and* q *is observed by both parties*

If q will be observed by the principal, the agent knows at time t=1 that he has no possibility of lying about q at time t=2. The solution to the optimal contract design in this case is found by minimizing (9) with respect to r^i_j and S^i_j subject to the binding constraints IR^2_2, IR^2, and $IC1^1$ given by (10), (11) and (4). Since q will be observed by the principal, we can ignore the incentive compatibility constraints ($IC2^i_j$), given by (6).

The solution to the optimal contract design is identical to the contract derived in section 3.1, (r^1_1 and r^1_2 are given by (12) and r^2_1, r^2_2, EP^1 and EP^2 are given by (16)- (19)). When q is observed by the principal the fact that the agent will breach the contract if P^2_2 <-g is not costly for the principal.

4.2. The optimal contract in the case where β *is known by both parties at time t=1, but the outcome of* θ *is observed only by the agent.*

At time t=0, the principal knows that there is a probability *v* that she will observe that the non-cooperating country is b^1-type and a probability (1-v) that it is a b^2-type if she acquires information about b. When the principal has observed b, she designs a contract at time t=1 that minimizes the cooperating countries' expected abatement cost given full information about b. At t=0 the optimal contract design of this policy is found by minimizing (9) with respect to r^i_j and S^i_j subject to the two binding individual rationality constraints IR^1_2 and IR^2_2 given by (11), and $IC2^1_1$ and $IC2^2_1$ given by (6). $IC2^1_1$ and $IC2^2_1$ are binding in the optimal contract because EP^1 is increasing in d^1 and EP^2 is increasing in d^2. d^1 and d^2 are therefore set equal to the lower bound of (7) and (8), respectively. We assume that g is small enough to ensure that IR^1 and IR^2, given by (10), are satisfied if IR^1_2, IR^2_2, $IC2^1_1$ and $IC2^2_1$ are satisfied.

The optimal contract design is characterized by:

$$-\frac{dD}{dr_2^2} = \frac{dC_2^2}{dr_2^2} + \frac{p}{1-p}\left(\frac{dC_2^2}{dr_2^2} - \frac{dC_1^2}{dr_2^2}\right) \tag{27}$$

$$-\frac{dD}{dr_2^1} = \frac{dC_2^1}{dr_2^1} + \frac{p}{1-p}\left(\frac{dC_2^1}{dr_2^1} - \frac{dC_1^1}{dr_2^1}\right) \tag{28}$$

and r^1_1 and r^2_1 given by (12) and (14).

It follows from the binding constraints IR^1_2, IR^2_2, $IC2^1_1$ and $IC2^2_1$ that the financial transfers specified in the contract give

$$E\Pi^2 = p\left[C_2^2(r_2^2) - C_1^2(r_2^2)\right] \quad -\gamma \tag{29}$$

$$E\Pi^1 = p\left[C_2^1(r_2^1) - C_1^1(r_2^1)\right] \quad -\gamma \tag{30}$$

We get the first-best solution for r^1_1 and r^2_1, but r^1_2 and r^2_2 are lower than first-best. The agent's private observation of θ forces the principal to trade off expected informational rent to both types of agents against efficiency losses. Since the principal does not observe θ she is forced to leave a non-negative informational rent to both types of agents in order to induce the agent to tell the truth about θ at t=2.The informational rent is increasing in the abatement demanded for the θ_2 -outcome of θ. The reason for this is that the difference in marginal abatement cost between θ_2 and θ_1 is higher the higher abatement demanded ($C^{//}_{r\theta} > 0$ for both types of agents).

4.3. Optimal contract when β is unobserved by the principal and θ will only be observed by the agent.

The optimal solution to the problem is found by minimizing (9) with respect to r^i_j and S^i_j subject to the binding constraints IR^2_2, $IC1^1$ and $IC2^2_1$ given by respectively (11), (4) and (6), and $d(b^2, \beta^1, \theta)$ given by (5) equals d_1.

The solution to the problem is characterized by:

$$-\frac{dD}{dr_2^2} = \frac{dC_2^2}{dr_2^2} + \frac{p}{1-p}\left(\frac{dC_2^2}{dr_2^2} - \frac{dC_1^2}{dr_2^2}\right) + \frac{v}{1-v}\left[\frac{1}{1-p}\left(\frac{dC_2^2}{dr_2^2} - \frac{dC_1^2}{dr_2^2}\right)\right] \tag{31}$$

and r^1_1 and r^1_2 given by (12) and r^2_1 given by (23).

It follows from the binding constraints IR^2, $IC1^1$ and $IC2^2_1$ that the financial transfers specified in the contract give

$$E\Pi^2 = p(C_2^2(r_2^2) - C_1^2(r_2^2)) - \gamma \tag{32}$$

$$\begin{aligned} E\Pi^1 &= C_2^2(r_2^2) - C_1^2(r_2^2) + C_1^2(r_1^2) - C_2^1(r_1^2) \\ &\quad + p(C_2^1(r_1^2) - C_1^1(r_1^2)) - \gamma \end{aligned} \tag{33}$$

We have assumed that γ is small enough to ensure that IR^1 and IR^2 are satisfied if IR^2_2, $IC1^1$, $IC2^1$ and $IC2^2$ are satisfied. This means that the agent's expected rent of accepting the contract is non-negative for both outcomes of β. If we compare (31) with (24), we find that r^2_2 is lower when the cost of breaching the contract is low than in the case where the cost of breaching the contract is high. There are two reasons for this. First, since the *ex post* individual rationality constraint (11) is binding when the cost of breaching the contract is low, a lower r^2_2 will reduce the expected rent to the β^2-type due the incentive compatibility constraint at time t=2 ($IC2^2_1$). Second, since the expected profit for the β^2-type is non-negative and increasing in r^2_2, the informational rent left to the β^1-type is also increasing in r^2_2. By reducing r^2_2, when the cost of breaching the contract is low, the principal reduces the payment needed to induce truth-telling at time t=1, more than in the situation where the cost of breaching the contract was high.

As we discussed in section 3.3, it is always profitable for the principal to design a contract where the agent has to announce the outcome of β at time t=1, instead of designing a contract where the agent announces β and θ simultaneously at time t=2 if both b and q are unobservable for the principal. When the agent does not have to announce b before q is observed, the expected profit given to the b^1-type in order to induce truthtelling is higher, than when the agent announced b before q was known. This implies that the principal can take advantages of the fact that q is unknown to the agent at the time of entering into the contract. The principal reduces the cooperating countries' abatement cost by designing a contract where the agent has to announce b at time t=1 and q at time t=2.

If the cost of breaching the contract is low it is beneficial for the principal that the agent knows the value of b before q is observed. If the agent did not observe the outcome of b before time t=2, the agent would be offered a contract at time t=1 that specified four different combinations of abatement levels and financial transfers {S,r}.[7] One combination designed for each of the four outcomes of {b,q} the agent announces at time t=2. The expected profit given to the agent would then be higher than in the contract derived in section 4.3 to induce truth-telling. This conclusion is opposed to the conclusion in section 3.3 where we concluded that if both b and q were uncertain to the agent at the time of signing the contract, the principal could design a first-best contract that was incentive compatible. In section 3.3 the agent's private knowledge of b when the contract was signed implied that the principal had to ensure that $EP^2 \geq 0$. However, if both b and q were unknown to the agent when the contract was signed the principal had only to ensure that $v \cdot E\Pi^1 + (1-v) \cdot E\Pi^2 \geq 0$. The latter binding individual rationality constraint implies that it is not costly for the principal to induce truthtelling. However, when the cost of breaching the contract is low, the binding individual rationality constraint is not affected by the fact that b is known or not when the contract is signed. The binding individual rationality constraint is in both situations given by (11), that is, $P^2_2 \geq -g$. It is beneficial for the principal that the agent knows b before q is observed because that reduces the b^1-type's truth-inducing informational rent. The abatement levels specified in the optimal contract if both b and θ are uncertain when the contract is signed, and will be announced *simultaneously* at time t=2, are identical to the abatement levels specified if both b and q are private knowledge to the agent when the contract is signed. If g had been equal to zero, the financial transfer would also be identical.

4.4. The value of acquiring information

The principal's abatement cost will always be higher when β is private information to the agent, than when β is common knowledge. Information about b implies that the principal does not have to give the agent an informational rent to induce truth-telling at time t=1.

Comparing the optimal contract in section 3.2 with 4.2 we see that if the principal has to ensure that the agent does not breach the contract for bad outcomes of q, observing b is not sufficient to achieve the first-best contract. It could therefore be beneficial for the principal to both acquire information about b before the agent was offered the contract and to design a contract where the principal monitored the outcome of q at time t=2.

The principal’s value of observing θ when β is private knowledge to the agent is higher when the agent’s cost of breaching the contract is low than when the cost of breaching the contract is high. When the cost of breaching the contract is high, observing θ would remove the β^1-type’s possibility of overstating θ at time t=2. This would, as discussed in section 3.3, imply that the informational rent in order to induce truth-telling at time t=1 would be decreased. However, if the cost of breaching the contract is low, observing θ means that the principal does not have to give the β^2-type an informational rent in order to induce truth-telling at time t=1. Furthermore, the informational rent left to the β^1-type can be reduced both because the expected profit left to the β^2-type would be zero when θ is observable *and* because observing θ would remove the β^1-type’s possibility of overstating θ at time t=2.

[7] In order to ensure that the contract is incentive compatible, r must be increasing in C, that is $r^1_1 \geq r^1_2 \geq r^2_1 \geq r^2_2$

5. Concluding remarks

In this paper we have considered a situation where a principal, representing countries cooperating to reduce global CO_2 emissions, offers an agent that represents a non-cooperating country, an abatement contract. We have assumed that some relevant information about the non-cooperating country's abatement cost function is private knowledge to the agent at the time when the contract is offered. However, the abatement cost is not completely known by the agent at that time. The agent will privately observe the complete abatement cost when various abatement projects have been implemented. Before designing the contract, the principal decides how much costly information she should try to obtain. The principal has two options for what time she could acquire information. Information about the non-cooperating country's expected abatement cost can be obtained before the contract is offered, or the principal can design a contract that will give her access to the same information as the agent obtains when implementing the various abatement projects. The latter type of information can be acquired if the principal monitored the implementation of the projects.

We have analyzed the gain for the principal of getting access to the same information as the agent. In the paper we have assumed that the principal cannot force the agent to fulfill the contract. Hence, if the agent, after observing all relevant information, realizes that it is less costly to quit the contract and get no payment than to fulfill the contract and get the payment specified in the contract, the agent will quit. In the paper we have considered two different situations regarding the agent's cost of breaching the contract.

If the agent learns the complete abatement cost at an early stage, that is, when only a few abatement projects have been implemented, the sunk cost of the agent's investment in abatement projects is low. We have refer to that situation as a situation where the agent's cost of breaching the contract is low. We assume that the cost of breaching the contract is so low that the principal has to take into account that she has to prevent the agent from breaching the contract, when she designs the optimal contract. If a lot of projects have been implemented before the complete abatement cost is learned, the cost of breaching the contract and hence get no payment could be very high. That situation is referred to as a situation where the agent agent’s cost of breaching the contract is high. We assume that the agent’s cost of breaching the contract, in that situation, is so high that the principal does not have to take into account that she has to prevent the agent from breaching the contract, when she designs the contract.

We have showed that private information at the time of entering into a contract is beneficial for the agent both when the cost of breaching the contract is low and when it is high. The optimal abatement contract in case of asymmetric information will leave the agent with a positive profit. Furthermore, the contract will not ensure cost-effective distribution of abatement between the non-cooperating country and the cooperating countries. Acquiring information before the contract is offered has therefore a positive value for the principal. Whether it is optimal to acquire information depends on the cost of obtaining information.

The principal's cost of the contract will be reduced if the agent announces its private information at the different points of time when the information is observed compared to a simultaneous announcement after both types of information have been observed.

If the agent’s cost of breaching the contract is high, we find that the principal can achieve the first best contract if she gets access to the same information as the agent has before the contract is offered. The distribution of abatement between the cooperating countries and the non-cooperating country is in that case cost-effective and the principal extracts all rent. In that situation there will be no additional benefit for the principal to monitor the implementation of the abatement projects. However, if the agent has some private information about the cost function before the contract is signed, private information obtained after the contract is signed will increase the agent’s expected profit. Monitoring the implementation of the abatement projects will hence in that situation increase the principal’s expected benefit of the contract (exclusive the cost of monitoring).

The principal's access to the same information as the agent has before the contract is signed will not be sufficient to ensure the first best contract if the agent's cost of breaching the contract is low. Private information after the contract is signed implies that the optimal contract will leave the agent with a positive expected profit. It could therefore be beneficial for the principal to monitor the implementation of the abatement projects even if she had the same information as the agent when the contract was signed.

The principal's value of monitoring the implementation of the various abatement projects is always higher when the agent's cost of breaching the contract is low than when it is high.

We have assumed that the agent is risk neutral. Assuming risk neutrality simplifies the presentation of the characteristics of the optimal contracts and emphasizes the trade-off between informational rent and efficiency losses in the different situations discussed in the paper. If the agent is risk averse, the uncertainty about the abatement cost implies that the principal has to give the agent a risk premium. This would reduce the principal's benefit of the contract. Moreover, the optimal contract would trade off both informational rent and risk premium against efficiency losses.[8]

A risk neutral agent enables us to illustrate the point that even though the agent is risk neutral and the cost of breaching the contract is high, access to private information after the contract is signed *in combination* with private cost observation at the time of contracting, reduces the principal's expected benefit of the contract. The agent's access to private information after the contract is signed forces the principal to increase the agent's expected profit of the contract in order to induce him to reveal truthfully his private information held at the time of entering into the contract.

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[8] Salanie (1990) shows that the agents̓ risk aversion also may play a critical role in the shape of optimal contracts. He shows that pooling will occur for large values of the agents̓ absolute risk aversion when the agent learns his private information after the contract is signed.

It can be argued that a developing country with very low income could be risk neutral for positive incomes but will not accept an abatement contract if there is a probability that it will get a negative profit. This is sometimes referred to as if the country has "infinite risk aversion below zero." That means the non-cooperating country will never accept a contract if not all outcomes of the abatement contract gave a non negative profit. In that case we would get the same optimal abatement contracts as if the agent's cost of breaching the contract was zero.

In the paper we have assumed that it is not possible for the principal to enforce the agent to fulfill the contract if the agent finds it more beneficial to breach the contract. The only instrument for inducing the agent to fulfill the target is the monetary transfer specified in the contract. However, this assumption may not be valid for all potential non-cooperating countries. The cooperating countries could, for example, prevent the non-cooperating country from breaching the contract through threats of trade sanctions or retention of loans. (The non-cooperating country could also fulfill the obligations specified in the contract, even though it would give a negative profit, if it wants to keep a good reputation in case of other climate contracts in the future). Unless the cost of monitoring is zero, the cooperating countries prefer to enter into a contract with a country that will never find it beneficial to breach the contract. It can therefore be beneficial for the cooperating countries to enter into a climate contract with a country they can “enforce” to not breach the contract.

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