CICERO

Working Paper 1998:10

Senter for klimaforskning

Center for International Climate and Environmental Research - Oslo

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ISSN: 0804-452X

CICERO Working Paper 1998:10

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December 1998

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[*] Comments from Knut H. Alfsen, Bjart Holtsmark and Asbjørn Torvanger have been highly appreciated. I gratefully acknowledge the financial support from the Research Council of Norway under the "Sustainable Production and Consumption" program and the SAMRAM program.

Abstract

The purpose of this paper is to compare the effect of different domestic climate policy instruments under asymmetric information when the regulator wants to secure the survival of a specific firm. It is a well-known result from economic theory that emission taxes lead to a cost-effective distribution of abatement across polluters. However, if the regulator wants to ensure the survival of a specific firm, it may need to design policy instruments that reduce the firm's cost of complying with an emission tax regime.

The climate policy instruments considered in this paper are tradable emission permits with distribution of free permits, emission taxes in combination with a fixed subsidy, and two types of voluntary agreements. It demonstrates first that distributing free tradable permits does not necessarily reduce the possibility of shutdown for a profit-maximizing firm, whereas emission taxes in combination with a fixed production subsidy can have a preventive effect. It further shows that a voluntary agreement where a specific abatement target is set by the regulator can prevent a shutdown but leads to lower welfare than the use of emission taxes in combination with a fixed subsidy. And finally it illustrates that a voluntary agreement designed as a menu of abatement contracts increases social welfare compared to an emission tax regime.

Contents

1 Introduction

The Kyoto Protocol sets quantified greenhouse gas emission limitations for developed countries for the period 2008–2012. This period is supposed to be the first in a series of "commitment periods." The protocol places no restrictions on the use of domestic policy instruments and allows developed countries to participate in emission trading. However, rules or procedures for emission trading among the developed-country parties have not yet been agreed upon. Due to this lack of rules, I assume in this paper that there will be no restrictions placed on trade in national quotas between governments in developed countries for the first commitment period under the Kyoto Protocol.[1]

In this paper, I examine a government's choice of domestic climate policy for the first commitment period under the Kyoto Protocol. A cost-effective domestic climate policy implies that marginal abatement costs are equalized across all sources of emissions. This is achieved if the government, henceforth referred to as the regulator, ensures that all sources of emissions face the same emission tax. Another alternative is the use of tradable emission permits.[2] Such permits could either be distributed free of charge to emitters or sold/auctioned.

Emission taxes and tradable permits sold by the regulator have an advantage over other environmental policy instruments that do not generate public revenue, such as command-and-control instruments or permits distributed free of charge. This is because emission taxes/sold tradable permits not only ensure that marginal abatement costs are equalized across all sources of emissions but also produce extra government revenue that could be used to reduce pre-existing distortionary taxes. The social benefit of policy instruments that generate public revenue is discussed in the literature on "double dividend." (See Goulder (1995) for an overview of some of this literature and different specifications of the term "double dividend," and Bohm (1997) and (1998) for a critical discussion of some of the issues discussed in the literature on "double dividend".

In this paper I have assumed that free trade in national quotas is allowed between governments in developed countries. If the regulator sets the national permit price/emission tax equal to the international quota price, domestic marginal abatement costs equal the cost of buying an additional quota on the international quota market. This ensures a cost-effective climate policy meaning that the country's total domestic abatement cost plus the income/expenditure from international quota trade is minimized, given the commitment under the Kyoto Protocol.

I assume in this paper that the regulator chooses environmental taxes or tradable permits, which are sold by the regulator, as the policy instrument faced by all emitters except the specific firm the regulator wants to ensure the survival of. Furthermore, I assume that the emission tax/domestic tradable permit price equals the international quota price. This implies in a tradable permit system that the regulator provides the domestic permit market with sufficient permits to ensure that the permit price equals the international quota price. The

[1] This assumption is not important for the conclusions drawn in the paper. However, assuming no restrictions placed on trade in national quotas simplifies the expression for the national social cost of emission from a polluting firm.
[2] The term "emission permit" is used to describe domestic traded emission allowances, while the term "quota" refers to internationally traded emission allowances.

tradable permit system and the emission tax system described above will, in the following discussion, be regarded as identical policy instruments. [3] The conclusion drawn in this paper about the consequences of the emission tax system will therefore also hold if the regulator chooses the tradable permit system. Furthermore, I have assumed that national quotas are traded between governments and not between firms. However, all conclusions in the paper will also hold if the regulator sells its allotment of quotas and domestic firms are allowed to trade national quotas on the international quota market.

Some countries—including Norway, Sweden, Denmark and the Netherlands—have already introduced carbon-taxes in order to reduce their CO_2 emissions. However, the tax systems are far from cost-effective, both because the tax rate differs across fuels and sectors and because several sectors are exempted from the carbon tax. Regulators often deviate from a cost-effective tax scheme because they expect such a scheme would reduce the competitiveness of some key industries. Indeed, there is no question that a cost-effective climate policy may lead to shutdown of certain firms with high abatement costs. The possibility of shutdown is higher if a firm competes with firms either from countries that do not have emission targets under the Kyoto Protocol (developing countries) or from other industrialized countries that continue to exempt certain industries from emission taxes.

Although closing down certain polluting firms can be a cost-effective climate policy in a strict economic sense, politicians may regard the negative social costs of closedowns as higher than the economic benefit of implementing a cost-effective climate policy. The firms in question can for instance be located in rural areas where there are few other employment opportunities for the local labor force. For this reason, there is a need for policy instruments that can both secure the survival of certain firms and induce the firms to choose the socially optimal abatement level.

I assume in this paper that the regulator wants to both minimize the cost of fulfilling the country's commitments under the Kyoto Protocol and ensure the survival of a specific polluter (firm).[4,5] I examine the situation where the regulator has less information about the firm's abatement cost than the firm itself has. The climate policies considered are a distribution of free permits under a tradable permit regime, a fixed production subsidy under an emission tax regime, and two types of voluntary agreements.

Pollution control under asymmetric information where the regulator seeks to ensure the survival of a firm has been analyzed in Jebjerg and Lando (1997). They argue that allocating

[3] Under both systems, the national government (the regulator) has to ensure, through trade in quotas on the international market, that the national emissions following from the emission tax/tradable permit sale plus its purchase /sale of quotas are in compliance with the national emission limitations under the Kyoto Protocol.
[4] Considering a case where the regulator seeks to achieve survival of several firms or a whole industry represented by a single well–informed representative would not alter the conclusion of this paper. This is discussed in the last section.
[5] An important concern in the design of international climate agreements with limited participation, such as the Kyoto Protocol, is the "carbon leakage" problem. Reduced emissions from participating countries may to some extent be counteracted by increased emissions from other countries. Several studies have focused on designing climate policy to reduce the carbon-leakage problem. (See for instance Golombek *et. al* (1995), Hoel (1996) and Mæstad (1998)). However, the starting point of this study is a single country that seeks to maximize its welfare, given that its commitment under the Kyoto Protocol is fulfilled. The impact on global emissions of its different choice of climate policy is not included in the national welfare function. The rationale for this assumption is that I consider a single country's choice of domestic climate policy instrument. The impact on global emissions through the carbon leakage following from a single country's choice of policy instrument will be small.

free emission permits to a firm can prevent a firm with high abatement costs from shutting down. In Norway, politicians have suggested that certain industries should receive pollution permits free of charge in order to limit their costs and hence prevent the industry from shutting down production. In section 4.1 I show that distributing free tradable permits does not, in general, secure the survival of the firm as long as there are no restrictions on the trade in permits and the firm seeks to maximize its profit. However, I show in section 4.2 that the regulator can secure the survival of the firm under a tradable permit/emission tax regime by giving the firm a sufficiently large subsidy contingent upon continued production.

Another policy instrument that can be used to prevent a shutdown is a so-called ”voluntary agreement” (VA). (See *inter alia* European Environmental Agency (1997), and Segerson and Miceli (1998) for an assessment of environmental effectiveness of VAs and OECD/IEA (1997) for a survey on voluntary agreements in International Energy Agency member countries.) The term “VA” covers a range of agreements, from emission target setting to agreement on the choice of technology or fuel substitution. VAs comprise both legally binding agreements and non-binding abatement declarations from an industry or firm.

VAs are not always truly voluntary. The regulator may for instance induce participation by threatening a harsher outcome. I assume in this paper that if the firm does not accept the “voluntary agreement” it will face the same emission tax/tradable permit regime as the rest of the economy. Furthermore, I assume that the regulator has all the bargaining power in the sense that it offers a take-it-or-leave-it agreement to the firm.[6] However, the regulator knows that if the firm does not accept the VA, the implication is that the firm finds it more profitable to close down production than to pay an emission tax. The firm’s credible threat of shutting down production if the voluntary agreement is too harsh thus sets restrictions on the “take–it-or-leave-it”offer.

In this paper I consider two kinds of voluntary agreements: In section 4.3 I examine an agreement designed as a target for abatement, set by the regulator, in combination with a financial transfer; in section 4.4 I discuss the welfare effect of designing a voluntary agreement as a menu of abatement contracts where the firm can choose among the different contracts.

It is a well-known result from the literature on contracts under asymmetric information that private information leaves the firm with a positive informational rent.[7] In this situation it is generally optimal for the regulator to design contracts that trade off efficiency for informational rent. This tradeoff is not possible under an emission tax system. Jebjerg and Lando (1997) point out that, because of the possibility of a tradeoff between efficiency and informational rent, abatement contracts lead to higher welfare than a lump-sum transfer (production subsidy) in combination with an emission tax/tradable permit system designed to prevent shutdowns.

In this paper, I consider a certain specification of a firm’s abatement-cost function, which implies that the regulator cannot increase welfare by trading off cost-effectiveness for informational rent. I demonstrate that *even though* the optimal abatement contracts do not

[6] Sergerson and Miceli (1998) analyse, among other things, how the agent’s bargaining power influences the environmental impact of voluntary environmental agreement.
[7] Surveys of this literature can be found in, for example, Hart and Holmstøm (1987), Kreps (1990) and Rasmussen (1989)

trade off cost-effectiveness for informational rent, a voluntary agreement designed as a menu of abatement contracts increases social welfare in comparison with an emission tax regime where survival of the firm is secured through a production subsidy.

In the next section I present the model. In section 3, I derive, as a benchmark, the impact of a cost-effective climate policy on the firm's production and abatement decision. The impact on social welfare of the different climate policies designed to prevent shutdown is discussed in section 4. Concluding remarks are given in the last section.

2 The model

The model is based on a situation where the regulator wants to secure the survival of a specific firm during the first commitment period under the Kyoto Protocol. The firm's abatement cost function is given by

$$C = C(a, \beta) \tag{1}$$

where a is abatement and β is a cost parameter privately known to the firm. The specification of the firm's abatement cost function considered in this paper is given in section 2.1. Throughout the paper I assume that abatement is observable.

The firm's total cost of the regulator's climate policy is, in addition to the cost connected to abatement, also a function of the possible financial cost associated with the purchase of permits, tax payment or subsidies from the regulator. The net financial transfer from the regulator to the firm is denoted by S.[8]

The firm shuts down its production if the expected profit of continued production under the climate policy is less than the profit achieved by shutting down. Let Π^0 denote the profit achieved from production in the first commitment period under the Kyoto Protocol, in the absence of any restrictions on emissions from the firm's production. Furthermore let $E\overline{\overline{\Pi}}$ denote the expected present-period value of maximum profit achieved in the periods after the first commitment period under the Kyoto Protocol. The present-value expected profit of continued production less the cost of the climate policy in the first commitment period, denoted by $\overline{\Pi}$, is hence given by

$$\overline{\Pi} = \Pi^0 + E\overline{\overline{\Pi}} \quad . \tag{2}$$

The firm's expected profit if it continues production under the climate policy, denoted by Π, is given by

$$\Pi = \Pi(a, \beta, S) = \overline{\Pi} + S - C(a, \beta) \tag{3}$$

The criterion for continued production is as follows:

Continue production if, and only if,

$$\Pi(a^*, \beta, S) \geq \Pi^{SD} \tag{4}$$

[8] If the regulator has chosen to use a tradable permit system, I assume that the firm buys permits directly from the regulator instead of buying permits from other firms. This specification of the model implies that the tradable permit regime and the emission tax regime can be described with identical equations. A tradable permit regime would lead to exactly the same result if I assumed that the firm buys the permit on the permit market since the regulator has to provide the domestic permit market with sufficient permits to ensure that the permit price equals the international quota price t.

where a^* is the firm's profit-maximizing choice of abatement given continued production under the climate policy set by the regulator, and Π^{SD} is the profit achieved if the firm shuts down. The criterion for continued production (eq. (4)) will be referred to as the individual rationality (IR) constraint.

The social welfare function if the firm continues production is

$$W = V + (1+\lambda)(t \cdot a^* - S) + \Pi \quad (5)$$

where V is the welfare associated with continued production in the first commitment period. The variable V is zero if the firm closes down, and it has a positive value if the firm continues production. The value of V is assumed to be sufficiently large to ensure that the regulator wants the firm to continue production for all outcomes of the abatement-cost functions examined. Furthermore, I assume that the regulator, in the design of a climate policy, seeks to ensure the survival of a firm only in the first commitment period. There are two arguments for this assumption. First, if survival of the firm is important to social welfare because of the lack of other employment opportunities in the areas where the firm's production plant is located, the social cost of a shutdown may substantially decrease if the local community has sufficient time to adjust to the expected decrease in employment. Second, harmonization of policy instruments across countries may imply, over time, that competing producers face the same emission tax/tradable permit price. Due to increased production cost for a large number of producers, the price of the product the firm produces may increase sufficiently to ensure a non-negative profit, even if the firm faces the same emission tax as the rest of the economy. Thus, the regulator may not have to take explicitly into account survival of the firm when designing its climate policy in future periods.

The shadow cost of public funds is denoted by λ. Because of pre-existing distortionary taxes, the value of λ is greater than zero. Abatement carried out by the firm would increase the regulator's sale (or decrease purchase) of quotas on the international quota market at a quota price t. The income from increased quota sale could be used to reduce distortionary taxes. Hence, the social welfare of abatement equals $(1+\lambda)\, t\, a^*$.

It follows from (3) that the social welfare function (5) can be written as

$$W = V + (1+\lambda)(t \cdot a^* + \overline{\Pi} - C(a^*, \beta)) - \lambda \Pi \quad (6)$$

It can be seen from (6) that social welfare decreases in Π (for a given $\overline{\Pi}$).
As pointed out in the introduction, I presume a certain specification of the firm's abatement cost. The abatement-cost function considered is described below.

2.1 Specification of the firm's abatement costs

This discussion looks at a firm for which abatement, a, occurs as a result of investments in "cleaner" production technologies. The number of investment possibilities is limited to two projects, denoted as K^I and K^{II}. The project K^I leads to an abatement of a^I units. By investing in the additional abatement technology, K^{II}, the firm can reduce its emissions by an additional

a^{II} units of emissions. Let I^{I} and I^{II} denote the cost of the investment projects K^{I} and K^{II}, respectively. The costs of the investment projects are given by

$$I^{I} = \beta a^{I}$$
and (7)
$$I^{II} = k\beta a^{II} \qquad k > 1$$

where k is a cost parameter which is public knowledge and β is the cost parameter which is known privately to the firm. This implies that the cost per unit abatement is lower for the a^{I} units of abatement achieved through the implementation of the K^{I} project than for the additional a^{II} units of abatement achieved through the K^{II} project, for the same outcome of the cost parameter β.

The firm has two options for abatement: implement both of the investment projects or implement only the investment project K^{I}. I will in the following refer to the abatement following from implementing only K^{I} as the low-abatement alternative, denoted by a_L, while implementing both investment projects is referred to as the high-abatement alternative, denoted by a_H. This leads to the following abatement costs:

$$\begin{aligned} C(a,\beta) &= \beta a \quad for \quad a = a_L \equiv a^{I} \\ &= \beta a_L + k\beta(a - a_L) \quad for \quad a = a_H \equiv a^{I} + a^{II} \end{aligned} \tag{8}$$

I consider the situation where β belongs to the two-point support $\{\beta^1, \beta^2\}$, where $\beta^1 < \beta^2$. If β is equal to β^1, I refer to the agent as a β^1-type, and refer to the agent as a β^2-type if β is equal to β^2. Let p denote the regulator's subjective probability for $\beta = \beta^1$.

The impact of assuming discontinuity in the distribution of β is discussed in the last section. The justification for this assumption is that I consider a firm where abatement occurs as a result of investment in new technology. It is reasonable to assume that the existing production technology has an impact on the firm's cost of installing and utilizing the new investment in abatement technology. If it is difficult for the regulator to observe the existing production technology, the abatement-cost function specified above can be a reasonable description of the situation.

I examine a situation where

$$\beta^2 < k\beta^1 < t < k\beta^2 \tag{9}$$

This implies that the unit cost of abatement is lower than the tax rate t for both outcomes of β for the investment project K^{I}. The unit cost of abatement resulting from the investment project K^{II} is lower than the tax rate for the β^1-type, but higher than the tax rate for the β^2-type.

3 The firm's adaptation to a cost-effective climate policy

In this section I derive the firm's decision of whether to continue production and the subsequent choice of abatement given that the firm faces the same emission tax as the rest of the economy. The net financial transfer from the regulator to the firm under an emission tax regime (S^t) is given by

$$S^t(a) = -t(\overline{E} - a) \tag{10}$$

where $\overline{E}$ is the emission level before any abatement has taken place and t is the emission tax set equal to the international quota price.

The firm can either close down or continue production. Substituting $S^t(a)$ for S in (3) leads to the following profit maximizing problem for the firm *if* it finds it profitable to continue production:

$$\underset{a \in \{a_L, a_H\}}{Max} \{\overline{\Pi} - C(a, \beta) - t(\overline{E} - a)\} \tag{11}$$

It follows from (8) and (9) that $\Pi(\beta^1, a_H) > \Pi(\beta^1, a_L)$ and $\Pi(\beta^2, a_H) < \Pi(\beta^2, a_L)$.
Let $a^{*t}(\beta)$ denote the firm's optimal choice of abatement as a function of the firm's abatement-cost parameter β given that the firm continues production. The function $a^{*t}(\beta)$ is hence given by

$$\begin{aligned} a^{*t}(\beta) &= a_L \ \ if \ \ \beta = \beta^2 \\ &= a_H \ \ if \ \ \beta = \beta^1 \end{aligned} \tag{12}$$

Equation (12) implies that $C(a^{*t}(\beta), \beta)) < t \cdot a^{*t}(\beta)$. Recall that t is emission tax faced by the rest of the economy. Profit maximization in the rest of the economy implies that domestic marginal abatement cost equals t, which is equal to the cost of buying quotas at the international quota market.

Hence, if the firm in question faces the same emission tax as the rest of the economy and continues production, the firm implements the abatement level for which the cost is less than the abatement-cost in the rest of the economy. Hence, $a^{*t}(\beta)$ is the cost-effective abatement level *given* that the firm continues production.

The firm continues production if (4) is satisfied for $a^* = a^{*t}(\beta)$.

I assume that the production capital is a sunk cost, so that the profit achieved by closing down the firm's production under an emission tax regime is zero ($\Pi^{SD} = 0$). The situation where a cost-effective climate policy induces the firm to shut down production is characterized by

$$\Pi(a^{*t}(\beta), S^t, \beta) = \overline{\Pi} + S^t - C(a^{*t}(\beta), \beta) < 0 \qquad (13)$$

where $S^t = -t(\overline{E} - a^{*t}(\beta))$

Obviously, closing down non-profitable emission-generating production is a cost-effective climate policy. However, the topic of this paper is the choice of climate policy instrument when the regulator attempts to prevent a shutdown that would occur should the firm face the same climate policy instrument as the rest of the economy. Hence, I look at a situation where (13) is satisfied.

In the remaining discussion, I refer to $a^{*t}(\beta)$ as the "second-best cost-effective abatement level," since $a^{*t}(\beta)$ is the cost-effective abatement level *given* that shutdown is prevented.

4 Policies designed to prevent shutdowns

In the following discussion, I will consider different policies designed to prevent a firm from closing down production. As mentioned in the introduction, I consider four different policy alternatives: tradable permits with an initial amount of free permits distributed to the firm, emission tax with a fixed production subsidy, a voluntary agreement designed as an abatement target, and a voluntary agreement designed as a menu of abatement contracts.

4.1 Distributing free tradable permits

As mentioned in the introduction, distributing free tradable permits to the firm that the regulator wants to secure the survival of has been suggested as a policy to prevent shutdowns. A prerequisite for a tradable permit market is that also firms other than the specific firm the regulator wants to survive hold tradable permits. Hence, I assume that the regulator has chosen a tradable permit regime for the rest of the economy if it chooses to distribute free tradable permits to the firm. Let $\overline{Q}$ denote the level of emission allowed by the permits distributed free of charge to the firm. Emissions above/below $\overline{Q}$ are met by a corresponding purchase/sale of tradable permits from/to the regulator. The net financial transfer from the regulator to the firm associated with this policy, denoted by S^P, is given by

$$S^P = -t(\overline{E} - \overline{Q} - a) \tag{14}$$

Substituting S^P for S in (3) leads to the following profit-maximizing problem for the firm if it continues production:

$$\underset{a\varepsilon(a_L,a_H)}{Max}\{\overline{\Pi} - C(a,\beta) - t(\overline{E} - \overline{Q} - a)\} \tag{15}$$

Let $a^{*P}(\beta)$ denote the solution to (15). Since $(t \cdot \overline{Q})$ is a constant and hence independent of a, this maximization problem will lead to the same optimal abatement level as the optimal abatement level following from the emission tax system described in section 3, if the firm continues production. Hence, $a^{*P}(\beta)$, equals $a^{*t}(\beta)$, as given by eq. (12). The firm's cost of the climate policy will, however, be $(t \cdot \overline{Q})$ less than in the tax system. But this will not alter the firm's decision regarding whether or not to close down. Since the permits are tradable, the firm sells its allotment of permits if it shuts down. The profit of closing down (Π^{CD}) thus increases with $(t \cdot \overline{Q})$ relative to the tax system. The criterion for continued production is thus to continue if, and only if,

$$\overline{\Pi} - t(\overline{E} - \overline{Q} - a^{*t}(\beta)) - C(a^{*t}(\beta),\beta) \geq t\overline{Q} \tag{16}$$

Both the right-hand side and the left-hand side of (16) increase by $(t \cdot \overline{Q})$ relative to the production criterion (IR-constraint) given by (4) under the emission tax regime. Distributing tradable permits free of charge does therefore not prevent a profit-maximizing firm from shutting down production should such a move prove to be profitable under the tax regime discussed in section 3. [9]

If restrictions are placed on the sale of permits, a shutdown can be prevented. However, restrictions on trade in permits undermine the cost-effectiveness achieved by a tradable permit regime.

Permits must be allocated to the firm in order to induce efficient permit trade. A firm that intends to shut down will sell its allotment of permits. Thus, the regulator cannot prevent the firm from earning ($t \cdot \overline{Q}$) from a closedown if the permits are fully tradable. Jebjerg and Lando (1997) argue (in section 4) that shutdowns can be prevented by distributing a sufficient amount of tradable permits. However, that conclusion follows from their assumption that if a firm's utility resulting from continued production falls below a specific level then it will close down production. That specific utility level is, in their model, unaffected by the amount of free permits. However, as argued above, if the permits are tradable, the utility (profit) resulting from closure increases by the value of the free permits (Π^{CD} increases by ($t \cdot \overline{Q}$)). The minimum utility level demanded by the firm for continuing production should therefore increase correspondingly.

4.2 Preventing shutdown through the use of a production subsidy in combination with an emission tax regime

The important difference between distributing free tradable permits and a production subsidy is that the production subsidy can be made contingent on continued production. The production subsidy can be paid to the firm at the end of the period or be designed as an annual payment when the regulator observes that the firm actually continues its production. Hence if the firm chooses to shut down production, the financial transfer is zero and thereby the profit achieved by shutting down would be zero.

The net financial transfer from the regulator to the firm in question, denoted by S^S, is given by

$$S^S = -t(\overline{E} - a) + \overline{S} \tag{17}$$

where $\overline{S}$ is a fixed subsidy paid to the firm contingent on continued production. Substituting S^S for S in (3) leads to the following profit-maximizing problem for the firm if it continues production:

$$\underset{a\varepsilon(a_L,a_H)}{Max} \{ \overline{\Pi} - C(a,\beta) - t(\overline{E} - a) + \overline{S} \} \tag{18}$$

Let $a^{*S}(\beta)$ denote the solution to (18). Since $\overline{S}$ is a constant and hence independent of a, this maximization problem will lead to the same optimal abatement level as the optimal abatement

[9] It is important to note that I assume that expected profit in future periods is identical under the two systems. If the firm anticipates that free emission permits in the first commitment period also implies free permits in future periods *if* the firm continues production, then the expected future profits would differ between the two systems. Free tradable permits would then reduce the possibility of a shutdown relative to the emission tax system.

level resulting from the emission tax system described in section 3, given that the firm continues production. Hence, $a^{*S}(\beta)$, equals $a^{*t}(\beta)$, as given by eq.(12). The firm's cost of the climate policy will, however, be $\overline{S}$ less than in the tax system described in section 3.

If $\beta = \beta^2$, the firm purchases permits for the amount $t \cdot (\overline{E} - a_L)$, whereas the firm purchases permits for the amount $t \cdot (\overline{E} - a_H)$ if $\beta = \beta^1$.

It follows from the IR constraint defined by (4), when a* = $a^{*S}\beta)$, that the $\overline{S}$ which ensures survival of the firm is a function β, and is given by

$$\overline{S}(\beta) \geq t(\overline{E} - a^{*S}(\beta)) + C(a^{*S}(\beta), \beta) - \overline{\Pi} \qquad (19)$$

If β were common knowledge, then the IR constraints would be binding for both outcomes of β since profit left to the firm is costly for the regulator. This implies that (19) is satisfied with equality. Consequently, the regulator could ensure, through the use of an emission tax in combination with a fixed production subsidy, that the firm continues production, carries out the abatement level $a^{*t}(\beta)$, which is the "second-best" cost-effective abatement level, and leaves the firm with zero profit.

However, since β is assumed to be private knowledge to the firm, the regulator must ensure that $\overline{S}$ is sufficiently large to ensure that the IR constraint is satisfied for both outcomes of β.

It follows from (8) that the IR constraint, (4), for the β^2-type, for a* = $a^{*S}(\beta)$, is satisfied with equality if

$$\overline{S} = t(\overline{E} - a^1) + \beta^2 a^1 - \overline{\Pi} \qquad (20)$$

Let $\Pi^{S\beta1}$ and $\Pi^{S\beta2}$ denote the profit achieved by the β^1-type and the β^2-type, respectively, when S is given by (17), a equals $a^{*S}(\beta)$, and $\overline{S}$ is given by (20). It follows from (3), (8) and (9) that

$$\begin{aligned} \Pi^{S\beta1} &= (\beta^2 - \beta^1) \cdot a^I + (t - k\beta^1) \cdot a^{II} > 0 \\ \Pi^{S\beta2} &= 0 \end{aligned} \qquad (21)$$

Asymmetric information forces the regulator to leave the β^1-type with a positive profit, henceforth referred to as an informational rent.[10]

In the following sections I compare the different climate policies with the outcome of the "emission-tax-with-a-fixed-production-subsidy" system described in this section. For that purpose I denote the expected social welfare following from the system described in this section EW^S. Recall that p is the regulator's subjective probability for $\beta = \beta^1$. It follows from (6), (8), (12) and (21) that

[10] It follows from the fact that $\Pi^{S\beta1}>0$, that the IR constraint for the β^1-type is satisfied for $\overline{S}$ given by (20).

$$EW^S = \begin{Bmatrix} V + p \cdot \begin{bmatrix} (1+\lambda)\cdot(t\cdot(a^I + a^{II}) + \overline{\Pi} - (\beta^1 \cdot a^I + k\beta^1 \cdot a^{II})) \\ -\lambda((\beta^2 - \beta^1)\cdot a^I + (t - k\beta^1)\cdot a^{II}) \end{bmatrix} \\ + (1-p)\cdot\left[(1+\lambda)\cdot(t\cdot a^I + \overline{\Pi}) - (\beta^2 \cdot a^I)\right] \end{Bmatrix} \tag{22}$$

The expected social welfare EW^S equals the expected social welfare of abatement less of the expected abatement cost and informational rent following from a production subsidy in combination with the emission tax regime.

4.3 Voluntary agreement designed as an abatement target plus a financial transfer

A voluntary agreement can specify a fixed target for abatement in combination with a fixed financial transfer. Given that abatement follows from investment in abatement technology as described in section 2.1, the regulator can set either a high or a low abatement target. In order to ensure that the firm does not shut down, the individual rationality constraint, given by (4), has to be satisfied. Let $S^{VA}(a)$ denote the financial transfer specified in the agreement as a function of the target level for abatement set by the regulator. Since the β^1-type of firm has lower abatement costs for both abatement levels than the β^2-type, the IR constraint for the β^1-type will be satisfied if the IR constraint for the β^2-type is satisfied. Since profit left to the firm is costly to the regulator, the IR constraint for the β^2-type is binding in the optimal contract. The financial transfer that ensures that (4) is satisfied with equality for the β^2-type is given by

$$S^{VA}(a) = C(a,\beta^2) - \overline{\Pi} \tag{23}$$

Substituting, $S^{VA}(a)$ for S in (3), gives the following profits depending on type and abatement targets:

$$\begin{aligned} \Pi^{VA}(a,\beta^1) &= C(a,\beta^2) - C(a,\beta^1) \\ \Pi^{VA}(a,\beta^2) &= 0 \end{aligned} \tag{24}$$

The regulator's optimization problem is

$$\underset{a\in\{a_H,a_L\}}{Max}\ EW = \begin{Bmatrix} V + p\cdot\left[(1+\lambda)\cdot(t\cdot a + \overline{\Pi} - C(a,\beta^1) - \lambda\Pi^{VA}(a,\beta^1)\right] \\ + (1-p)\cdot\left[(1+\lambda)\cdot(t\cdot a + \overline{\Pi} - C(a,\beta^2)) - \lambda\Pi^{VA}(a,\beta^2)\right] \end{Bmatrix} \tag{25}$$

subject to (24).

Whether a_L or a_H is the solution to (25) depends on the probability distribution for β and the informational rent following from the difference between β^1 and β^2.

Let $EW^{FA}(a_L)$ and $EW^{FA}(a_H)$ denote the expected welfare resulting from abatement targets a_L and a_H, respectively.

Inserting from the cost functions, given by (8), I find that

$$\begin{aligned} EW^{FA}(a_L) - EW^{FA}(a_H) &= \lambda \cdot p \cdot k(\beta^2 - \beta^1) \cdot a^{II} \\ &\quad - (1+\lambda) \cdot \left[t - k \cdot (p\beta^1 + (1-p)\beta^2) \right] \cdot a^{II} \end{aligned} \tag{26}$$

Recall that the difference in abatement between the a_L and a_H targets is a^{II}. The first term of (26) is the expected difference in social welfare resulting from the expected difference in informational rent between the a_L and a_H abatement targets. The second term of (26) is the expected difference in social welfare resulting from the difference in social benefit of abatement less the expected abatement cost, between the a_L and a_H abatement targets. The first term of (26) is positive and increases as the difference between β^1 and β^2 increases, while the second term can be positive or negative depending on the probability distribution.

Comparing the expected welfare of an emission tax regime with a production subsidy described in section 4.2 and the voluntary agreement described in this section gives the following differences in expected social welfare:

$$\begin{aligned} &EW^S - EW^{FA}(a_H) = \left[(1-p) + \lambda \right] \cdot (k\beta^2 - t) \cdot a^{II} \quad > 0 \quad \text{since} \quad k\beta^2 > t \\ &\text{and} \\ &EW^S - EW^{FA}(a_L) = p \cdot (t - k\beta^1) \cdot a^{II} \quad > 0 \quad \text{since} \quad k\beta^1 < t \end{aligned} \tag{27}$$

When the regulator sets a single target for abatement, one of the β–types' abatement will differ from the "second-best cost-effective abatement level." If the regulator chooses a_L as the abatement target, the informational rent to the β^1-type is less than that under an emission tax in combination with a production subsidy. However, the increase in expected social welfare resulting from the decrease in the expected informational rent is less than the expected decrease in social welfare following from the fact that the β^1-type's abatement deviates from the "second-best cost-effective abatement level." If the regulator chooses a_H as the abatement target, the informational rent to the β^1-type is higher than under an emission tax in combination with a production subsidy. Furthermore, the β^2-type's abatement will differ from the "second-best cost-effective abatement level."

This leads to the following conclusion:

Emission tax in combination with a fixed production subsidy leads to higher social welfare under asymmetric information than a voluntary agreement designed as a single target for abatement in combination with a fixed transfer.

4.4 Voluntary agreements designed as a menu of abatement contracts

I will now consider an alternative voluntary agreement design. In this scenario, the firm would be allowed to choose between two different combinations of financial transfer (S^C) and abatement level (a^C). One of the contracts is designed for the β^1-type and the other contract is designed for the β^2-type. Let $\{S^C(\beta^1), a^C(\beta^1)\}$ denote the combination of financial transfer and abatement level in the contract designed for the β^1-type, and let $\{S^C(\beta^2), a^C(\beta^2)\}$ denote the combination of financial transfer and abatement level in the contract designed for the β^2-type. Applying the Revelation Principle established in Dasgupta *et al*. (1979) and Myerson (1979), I can restrict the attention to incentive-compatible contracts. The incentive compatibility (IC) constraint makes certain that the contract designed for a given β-type is the preferred contract for that β-type. The IC constraints for the β^1-type and β^2-type amount to, respectively:

$$IC_{\beta=\beta^1} : \overline{\Pi} + S^C(\beta^1) - C(a^C(\beta^1),\beta^1) \geq \overline{\Pi} + S^C(\beta^2) - C(a^C(\beta^2),\beta^1)) \quad (28)$$

$$IC_{\beta=\beta^2} : \overline{\Pi} + S^C(\beta^2) - C(a^C(\beta^2),\beta^2) \geq \overline{\Pi} + S^C(\beta^1) - C(a^C(\beta^1),\beta^2)) \quad (29)$$

Let $\Pi^C(\beta^i)$ (i=1,2) denote the profit achieved by the β^i -type if it chooses the contract design for its type. The individual rationality (IR) constraints for the β^1-type and β^2-type when they select the contract designed for them of amount to, respectively:

$$IR^C_{\beta=\beta^1} : \Pi^C(\beta^1) = \overline{\Pi} + S^C(\beta^1) - C(a^C(\beta^1),\beta^1) \quad \geq 0 \qquad (30)$$

$$IR^C_{\beta=\beta^2} : \Pi^C(\beta^2) = \overline{\Pi} + S^C(\beta^2) - C(a^C(\beta^2),\beta^2) \quad \geq 0 \qquad (31)$$

I assume that if the firm is indifferent to the two contracts, it chooses the contract designed for its type. It follows from the abatement-cost function (8) and the fact that (β^2- β^1) >0, that the β^1-type has a lower cost than the β^2-type for both levels of abatement. This implies that (30) is satisfied if (28) and (31) are satisfied. I can hence ignore (30) in the regulator's optimization problem. I furthermore temporarily neglect (29) in the regulator's regulation optimization problem and later check that the solution to the minimization problem under (28) and (31) satisfies (29). Since profit left to the firm is costly to the regulator, the constraints (28) and (31) will be binding at the optimum, which implies that

$$\begin{aligned} &\Pi^C(\beta^1) = C(a^C(\beta^2),\beta^2) - C(a^C(\beta^2),\beta^1) \\ &\Pi^C(\beta^2) = 0 \end{aligned} \qquad (32)$$

I assume that it is beneficial for the regulator to induce abatement for both outcomes of β. The implication of this assumption is discussed in footnote number 12.

The regulator-optimization problem is

$$\underset{a^C(\beta^1),a^C(\beta^2)\in\{a_H,a_L\}}{Max\ EW} = \left\{ \begin{array}{l} V + p\cdot\left[\begin{array}{l}(1+\lambda)\cdot(t\cdot a^C(\beta^1)+\overline{\Pi}-C(a^C(\beta^1),\beta^1)) \\ -\lambda\Pi^C(\beta^1)\end{array}\right] \\ +(1-p)\cdot\left[\begin{array}{l}(1+\lambda)\cdot(t\cdot a^C(\beta^2)+\overline{\Pi}-C(a^C(\beta^2),\beta^2)) \\ -\lambda\Pi^C(\beta^2)\end{array}\right]\end{array}\right\} \quad (33)$$

subject to (32).

Let $a^{C*}(\beta^1)$ and $a^{C*}(\beta^2)$ denote the solution to (33). It follows from (8), (9), and (32) that $a^{C*}(\beta^1)$ and $a^{C*}(\beta^2)$ are given by a_H and a_L respectively.[11] This is identical to the abatement resulting from the emission tax regime with a production subsidy ($a^{*S}(\beta)$). I have assumed that it is beneficial for the regulator to induce abatement for both outcomes of β.[12] The regulator does therefore not decrease the informational rent given to the β^1-type by requiring the β^2-type to achieve a lower level of abatement than a_L. (The quantity a_L is the lowest abatement level possible if investment in abatement technology is to be implemented). Hence, the usual optimal tradeoff between cost-effectiveness and informational rent in the design of contracts under asymmetric information does not occur for the specific abatement-cost function considered in this paper.

The abatement level $a^{C*}(\beta^1)$ equals a_H because that is the abatement level that maximizes the social benefit of abatement less the abatement cost for the β^1-type, and $a^C(\beta^1)$ does not influence the informational rent. Let $\Pi^{C*}(\beta^1)$ and $\Pi^{C*}(\beta^2)$ denote the profit achieved by the β^1-type and the β^2-type, respectively, through the use of optimal abatement contracts. It follows from (8) and (32), since $a^{C*}(\beta^2)$ equals a_L, that the optimal contract design leads to the following profits:

$$\begin{aligned} &\Pi^{C*}(\beta^1) = (\beta^2-\beta^1)\cdot a^1 \\ &\Pi^{C*}(\beta^2) = 0 \end{aligned} \quad (34)$$

Comparing the emission tax system described in section 4.2 with the abatement contracts described in this section, one can see that the expected welfare resulting from the use of contracts, denoted by EW^C, is higher than the expected welfare resulting from the use of an emission tax in combination with a production subsidy.

The difference in expected welfare (ΔEW) between the two systems is given by

$$\Delta EW \equiv EW^C - EW^S = \lambda\cdot p\cdot(t-k\beta^1)\cdot a^{II} \quad > 0 \quad (35)$$

This leads to the conclusion that a so–called voluntary agreement designed as a menu of truth-inducing contracts is superior to the use of market-based instruments when the regulator aims to ensure the survival of a firm under asymmetric information. The regulator's cost in terms

[11] It follows from (32) that this solution implies that (29) is satisfied.

[12] This assumption implies that the expected social cost of informational rent left to the β^1-type for $a^{C*}(\beta^2)=a_L$ is less than the expected social benefit less of the abatement cost, of the abatement level a_L carried out by the β^2-type. If this had not been the case, $a^{C*}(\beta^2)$ should equal zero.

of expected informational rent is less when the regulator forces the firm to choose between contracts than it is under an emission tax regime.

5 Concluding remarks

This paper aims to compare the welfare effect of different domestic climate policy instruments under asymmetric information when the regulator seeks to secure the survival of a specific firm. I have demonstrated that free distribution of tradable permits under a tradable permit regime does not reduce the possibility of a shutdown compared to a situation where the permits are sold to the emitter.

To prevent shutdown under a tradable permit/emission tax regime, the firm can be given a production subsidy. An alternative policy is to use voluntary agreements. I have shown that a voluntary agreement that specifies a fixed abatement target is welfare inferior to a tradable permit/emission tax regime in combination with a production subsidy. A voluntary agreement designed as a menu of abatement contracts, on the other hand, leads to higher expected welfare under asymmetric information than a tradable permit/emission tax regime with a production subsidy.

The abatement levels specified in the abatement contracts can be perceived as non-tradable permits. An argument for the use of emission taxes is that the firm internalizes the social cost of emissions and hence chooses the cost-effective abatement level. This system ensures that, even though the regulator does not know anything about the firm's abatement cost, the firm will choose a cost-effective abatement level. However, cost-effective abatement may imply that the firm shuts down its production. When the regulator seeks to ensure survival of the firm, the asymmetry of information about the firm's abatement cost is costly for the regulator. In such a case, the regulator increases social welfare by forcing the firm to choose *ex ante* between different contracts specifying different combinations of abatement levels and financial transfers, rather than giving the firm a fixed financial transfer and leaving the firm to choose its abatement level.

It is well known that in the case of asymmetric information, it is generally optimal for the regulator to design contracts that trade off efficiency for informational rent. Such a tradeoff is not possible under an emission tax regime with a fixed financial transfer. In this paper I have examined a specific abatement-cost function where the cost parameter can take one of two values and where there are two possible levels for abatement.

This specification of the abatement-cost function implies that it is not optimal for the regulator to trade off cost-effectiveness for informational rent in the design of optimal abatement contracts. Hence, the paper shows that voluntary agreements may increase welfare compared to a tax regime *even though* the two different policies lead to the same expected abatement level — which is cost-effective *given* that the firm continues production. If the abatement-cost function were a continuously differentiable function of abatement (or if there were two possible abatement levels, but the cost parameter were continuously distributed over a given interval), the regulator would trade off efficiency for informational rent in the optimal design of abatement contracts. And as shown in Jebjerg and Lando (1997), the possibility for this tradeoff increases the social welfare resulting from optimal abatement contracts relative to the use of market-based instruments in combination with a fixed transfer.

I have considered the situation where a regulator seeks to ensure the survival of a specific firm. However, as noted in the introduction, the regulator may want to secure survival of an entire industry comprising a number of firms.

The conclusion drawn in this paper nevertheless remains the same given that a) the regulator designs climate policies for each specific firm it wants to ensure survival of, or b) the regulator designs a climate policy for the entire industry and that industry is represented by a single well-informed representative who maximizes the industry's total profit. In the latter case, the abatement refers to the entire industry's abatement and the abatement-cost function used in this paper represents the entire industry's abatement cost.

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