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National Climate Policy, Firm Survival, and Investments

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Abstract

In this paper we consider how to design a national tradable quota system to reduce emissions of climate gases when the regulator is concerned about the survival of specific firms. The problem is studied using a two-period model with a stochastic price in the second period. This enables us to include the effects of a chosen design of the tradable quota system on irreversible investment in abatement technology. We look at the social cost of ensuring firm survival for different ways of allocating free quotas and for different assumptions of whether an investment in abatement technology is cost minimizing or not.

Key Words: Environmental regulation, environment and technology, international environmental issues, tradable quotas, firm survival, climate policy.

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1 Introduction

Emissions of climate gases and their effects on the global climate have been debated for many years both among scientists and within the community of nations. There is now a wide recognition of the necessity of international binding commitments to reduce greenhouse gas emissions. In this regard, the Kyoto Protocol to the United Nations Framework Convention on Climate Change represents an important step towards regulating these emissions. The Kyoto Protocol requires the participating developed countries to reduce their collective emissions of six key greenhouse gases by 5.2% below 1990 levels during the period 2008–2012. Although the details have not yet been fully negotiated, the Kyoto Protocol also includes the possibility for the participating countries to reach their emissions goals through the use of several flexible mechanisms (the Kyoto mechanism), among them the possibility for emissions trading with other countries that have emission obligations under the treaty. The flexible mechanisms in general, and specifically the possibility of emissions trading among agents, are important instruments for reducing the costs of emissions abatement by allowing the parties to take cost-effective actions.

An international system of emissions trading will leave the choice open to each participating country of how to regulate greenhouse gas emissions domestically. However, there are advantages to combining an international tradable quota system with a national tradable quota system, and governments may thus be tempted to choose a tradable quota system at the domestic level (Bohm (1999) discusses this issue).

A national quota trading system that fulfils the requirements of the Kyoto Protocol will imply a cost for most agents operating within the system because they will have to abate emissions and/or buy quotas. For some firms, the increasing cost following from the climate policy can result in a situation where further production is not profitable. These firms may find it profitable to close down their production. The government may wish to prevent a situation like this for two reasons. First, if production is closed down in a country with commitments to reduce emissions, the *global* emissions from these sources are not necessarily reduced, and may in fact be increased depending on the intensity of emissions in the production of these goods in countries not having emissions obligations under the Kyoto Protocol. (This is often referred to as the carbon-leakage problem).¹ Second, survival of some firms may be important to social welfare because they are located in regions where the potential for establishing alternative businesses can be limited at least in the short run. This is probably the most important reason for individual governments to prevent domestic firms from closing down production.

We consider a situation where the government in a specific country has signed an international agreement to reduce emissions of climate gases and that an international system of tradable quotas has been established.² The government has elected to use tradable quotas on a national basis to reach the target agreed for the country. The relevant production decision for the firms we are considering is either to produce at the capacity level or to shut down production

¹ Several studies have focused on designing climate policy to reduce this problem. See for instance Golombek *et. al* (1995), Hoel (1996) and Mæstad (1998).

² This assumption is not crucial for the conclusions in this paper. We would get the same conclusions if only a national tradable quota system was established.

permanently.³ The government wants to secure the survival of the firms because of the employment following from production at the capacity level and/or the carbon-leakage consequences of firm closure. We analyze the problem in a dynamic context to be able to also include the effects of selected design elements on investment decisions in abatement technology in these firms.

We assume that the government in the country we are considering has decided to introduce an emissions-trading system domestically. All firms in this specific country must hold quotas corresponding to their emissions levels, and quotas can be bought on the international quota market. The government sells its initial endowments of quotas in accordance with the international agreement on the international market for quotas, except for the amounts allocated free of charge to firms where survival should be secured. These free quotas are allocated on a firm-specific basis contingent on continued production.⁴ In the discussion about the merits of using free quotas on a national basis it is normally assumed that the quotas are allocated on a general basis for instance by allocating quotas to firms based on historical emissions. Although simpler, a general allocation system is likely to be more costly since there will necessarily be a great deal of variation in the amount of free quotas required by each firm to secure survival. A general system thus runs risk of systematic over-allocation to some firms and allocating an insufficient amount of quotas to other firms. For this reason, this paper assumes firm-specific allocation.

Free quotas as a policy instrument to ensure survival of firms has been studied in Jebjerg and Lando (1997) and Hagem (1998). The authors study the impact of allocating free quotas when the firm in question has private information about its abatement costs. They both show, with different assumptions about the abatement cost function, that designing a menu of different abatement contracts, from which the firm can choose, is welfare superior to distributing free quotas contingent on production.

Several authors have addressed the issue of environmental policy and plant location. Markusen et al (1993 and 1995) analyze a model within the area of environmental policy where plant locations and market structures are endogenous. Their model demonstrates that plant location and market structure can be a function of environmental policy. Hoel (1997) follows up the studies by Markusen et al (1993 and 1995). He shows that in a game between the governments of two countries within this setting, each chooses its own environmental policy, and the Nash equilibria of the game are generally not Pareto-optimal. Hence, a coordination of environmental policy may be needed. The conclusion from Hoel (op.cit.) modifies the conclusion from Oates and Schwab (1988, 1996) that under certain assumptions, decentralization of emission taxes to the country level yields a Pareto-optimal outcome, so that there is no need for international coordination of emission taxes.⁵

3 In many countries it is a concern that taxes on greenhouse gas emissions from emissions-intensive industry or auctioned emissions quotas will lead to a shut down of several production plants within that industry. Emissions-intensive industries include manufacturing of metals, where characteristics of the production process are that the production capacity is given (in the short run), production involves a large fixed cost, and unit operating costs are constant. This implies that it is profitable for the firm either to produce at its full capacity, or to permanently or temporarily close down production.

4 Free quotas distributed unconditionally, that is, not contingent on continued production, does not prevent a firm from closing down production. This is discussed inter alia in Frech (1973) and Hagem (1998).

5 The assumptions of price-taking agents and small countries from the results obtained by Oates and Schwab (op cit.) are relaxed in the study by Hoel (op cit.).

Several authors have also considered another element of our problem, namely the effects of environmental policy on investment in new technology. Milliman and Prince (1989) consider firm incentives to promote technological change under five regulatory regimes: direct controls, emission subsidies, emission taxes, free marketable quotas, and auctioned marketable quotas. The process of technological change is broken into three basic steps: innovation, diffusion (facilitating the adoption of the new technology across firms), and optimal agency response (pressuring regulators to adjust pollution controls in response to these innovations). On a relative basis, taking into account all these steps, emission taxes and auctioned quotas provide the highest firm incentives to promote technological change; at times, free quotas generate lower incentives. Direct controls usually provide the lowest relative firm incentives to promote technological change. Jung et al (1996) extend Milliman and Prince's comparative approach from the firm to the industry level, and their rankings on the industry level are generally consistent with the firm-level findings of Milliman and Prince (op.cit.).

In our paper we do not analyze the strategic element of environmental policy when market structures are endogenous, but consider only how the government in a specific country can ensure firm survival through the design of its environmental policy. Further, we only consider one specific policy instrument, namely the allocation of free quotas—more specifically, how different systems for allocation of free quotas over time influence production and investment decisions. We look at the cost of ensuring firm survival under different systems of allocating free quotas and under different assumptions of whether an investment in abatement technology is cost minimizing or not. The next section presents the model used in the analysis. Section three describes the different designs of a national quota trading system that we are considering in this paper. Sections four and five compare different designs of a tradable quota system under different assumptions about the profitability of investment in different kinds of technology, and section six presents the conclusions of the paper.

2 The model

We consider a situation where a government in a country has signed an international climate agreement to reduce emissions of climate gases. The climate agreement specifies a particular target of emissions reductions for the different signatories. The target is set for a finite time horizon, which we divide into two periods, period 1 and period 2. The government in the country we are considering has decided to reach the target by introducing an emissions trading system. We assume that an international quota market with a quota price of t_i has been established, where $i=1,2$ indicate the period. The national firms must hold quotas corresponding to their emissions levels, and they are allowed to trade quotas on the international quota market. As stated in the introduction, the government sells its initial endowments of quotas according to the Kyoto Protocol on the international quota market, except for the amounts allocated free of charge to firms where survival should be secured. The government considers how to allocate the free quotas on a firm-specific basis to secure survival of these firms. In this paper we consider the implications of different allocation rules on production and investment decisions for one specific firm.

The firm has a fixed production capacity and constant unit operating costs. The relevant production decision for the firm in question is either to produce the capacity output or to permanently close down production.

Let x_i denote the firm's production in period i . Furthermore let the capacity output be normalized to 1. We assume that a temporary shutdown is not profitable for the firm, which means that if it is not profitable for the firm to produce in period 1, it will close down production permanently and hence not produce in period 2. Since we have assumed that it is always profitable for the firm to produce the capacity output if it chooses to not close down production, the different possible combinations of production in period 1 and 2 are hence

$$\{x_1, x_2\} \in \{\{0,0\}, \{1,0\}, \{1,1\}\} \quad (1)$$

Although the production capacity is fixed, we assume that the firm can reduce the emissions per unit output through investment in abatement technology. The firm decides if it is going to undertake this kind of investment in period 1. The emissions from the firm are dependent upon the level of production ex post and the technology (T) chosen by the firm

$$\varepsilon_i = g(x_i, T) \quad (2)$$

Here technology is given a wide interpretation. It could include both investments in abatement technology as well as investment in technological equipment that leads to a switch of energy source. (For simplicity we assume that a switch of energy source will not affect the production costs of the firm.) We assume proportionality between emissions and the level of production ex post. Further, investments in technology that reduces emissions from the firm are restricted to one project, denoted T^V . The technology that is already in use by the firm is denoted T^0 . There are hence three possible outcomes for the firm's emission levels, depending on whether the firm produces and the chosen technology:

$$\begin{aligned} g(0, T^j) &= 0 & j &= V, 0 \\ g(1, T^j) &\equiv U(T^j) & j &= V, 0 \end{aligned} \quad (3)$$

Emissions resulting from the existing technology, T^0 , are greater than emissions following from investment in the new technology, T^V , that is,

$$U(T^V) < U(T^0) \quad (4)$$

The authorities, henceforth referred to as “the regulator,” observe the emissions from the firm. The regulator uses the distribution of free quotas as the policy instrument to prevent the firm from closing down production. Since the quotas are fully tradable on an international market for quotas, they can be considered a monetary subsidy. The subsidies are given as free quotas allocated to the firm for each of the two periods. Let S_i denote the monetary value of the free quotas distributed in period i . The actual subsidies paid to the firm in each period are contingent on production. We assume that the regulator does not set any other demands for the distribution of quotas than that the firm must produce the capacity output, which we have assumed is the profit-maximizing output for the firm if it chooses to continue production. The free quotas, S_i , are given by

$$\begin{aligned} S_i &= 0 \text{ for } x_i < 1 \\ S_i &= s_i \text{ for } x_i = 1 \end{aligned} \quad (5)$$

Furthermore, let D_i denote the short-run profit of the firm if it chooses to produce (the capacity output) in period i . The short-run profit of the firm in period i (D_i) is given by

$$D_i = p_i - c_i - t_i U(T) + s_i \quad (6)$$

where p_i is the output price of the firm’s product in period i and c_i is the production cost at the capacity level. It is assumed that all agents have perfect foresight about both c_2 and t_2 in period 1. However, p_2 is assumed to be uncertain in period 1, and can either be high, with probability γ , or low with probability $1-\gamma$ ($0 \leq \gamma \leq 1$).⁶ A high level of p_2 is denoted p_2^H , and a low level of p_2 is denoted p_2^L . The division of p_2 into two levels – high and low – is motivated by the influence of other countries’ national climate policy on the price level in period 2. If other countries participating in the climate agreement choose to subsidize their industries that are in danger of being closed down, p_2 will have a low level. The opposite situation will give a high level of p_2 . It is assumed that without requirements of reducing emissions the firm will continue to produce the capacity output without any subsidies from the regulator. However, with requirements of emission reductions it is assumed that without a subsidy from the regulator in period 1 the firm will be closed down.

If the firm chooses to produce in period 1 ($x_1=1$), it will consider investing in technology T^V instead of keeping the old technology T^0 that results in higher emission levels. Throughout

⁶ An uncertain c_2 or t_2 in our model leads to the same qualitative results as an uncertain p_2 .

the paper, we assume that the cost of investing in T^V will not be covered by producing only in one period. Hence,

$$qT^V > t_i[U(T^0) - U(T^V)] \quad i = 1, 2 \quad (7)$$

where q is the unit price of T^V . The cost minimizing technology if the firm produces in only one period is therefore T^0 . We consider two different situations regarding the long-run impact on the firm's cost of the investment in abatement technology if the firm produces in both periods. We refer to the investment in T^V as a long-run cost minimizing investment if the following condition is satisfied:

$$t_1[U(T^0) - U(T^V)] + t_2[U(T^0) - U(T^V)] \geq qT^V \quad (8)$$

Equation (8) is satisfied if the total cost reduction over both periods following from the investment is higher than the investment cost. The situation where (8) is satisfied is analyzed in section 5.

If (8) is not satisfied, the existing technology T^0 is the cost-minimizing technology also if the firm produces in both periods. This situation is analyzed in section 4.

We assume that the firm is risk neutral. The firm will invest in T^V if the expected long-run profit (where long-run profit is denoted Π) from this investment is higher than the expected long-run profit earned with the technology T^0 , i.e.,

$$E[\text{Max}\Pi(T^V, x_1, x_2) - \text{Max}\Pi(T^0, x_1, x_2)] \geq 0 \quad (9)$$

The firm chooses the production in each period that maximizes the short-run profit given the investment decision in period 1. The three possible outcomes of the production decision are given by (1).

$$\begin{aligned} \Pi(T^V, x_1, x_1) &= \Pi_1(T^V, x_1) + \Pi_2(T^V, x_2) = \\ & p_1x_1 - c_1(x_1) - t_1\mathcal{E}(x_1, T^V) - qT^V + S_1 \\ & + p_2x_2 - c_2(x_2) - t_2\mathcal{E}(x_2, T^V) + S_2 \end{aligned} \quad (10)$$

$$\begin{aligned} \Pi(T^0, x_1, x_1) &= \Pi_1(T^0, x_1) + \Pi_2(T^0, x_2) = \\ & p_1x_1 - c_1(x_1) - t_1\mathcal{E}(x_1, T^0) + S_1 \\ & + p_2x_2 - c_2(x_2) - t_2\mathcal{E}(x_2, T^0) + S_2 \end{aligned} \quad (11)$$

We assume that the regulator wants to secure production in both periods both at a high and a low level of p_2 by allocating the minimum amount of free quotas necessary to achieve this. As discussed earlier, the relevant production decision for the firm in our model is either to produce the capacity output or to shut down production. Thus, for the government, securing production means to secure production at the capacity level.

3 Allocation rules

The regulator considers three different ways of allocating quotas (S_1, S_2) to the firm to secure production in both periods. The amount of free quotas distributed to the firm for period 1 is known to the firm at the beginning of period 1 under all allocation rules. The allocation rules differ regarding rules for allocating free quotas in period 2 if the firm continues production. Under all allocation rules, the amount of free quotas equals zero if the firm does not produce.

3.1 The flexible option

The amount of free quotas for period 2 is not announced by the regulator before the beginning of period 2, after the outcome of p_2 has been observed. We denote the amount of free quotas under this allocation rule as \tilde{s}_1 and \tilde{s}_2 .

The firm expects that the amount of \tilde{s}_2 allocated, denoted $E\tilde{s}_2$, is the amount that minimizes the amount of free quotas necessary to fulfill the regulator's goals for production and investment by the firm for that period.

3.2 The semi-flexible option

The amount of free quotas allocated in period 2 is a function of p_2 . This function, denoted $\hat{s}_2(p_2)$ is announced to the firm at the beginning of period 1. The outcome of $\hat{s}_2(p_2)$ is known to the firm when the regulator learns about the price level in period 2. The amount of free quotas in period 1 under this allocation rule is denoted \hat{s}_1 . The firm's expected amount of \hat{s}_2 allocated, denoted $E\hat{s}_2$, is

$$E\hat{s}_2 = \gamma\hat{s}_2(p_2^H) + (1 - \gamma)\hat{s}_2(p_2^L)$$

3.3 The fixed option

We denote the amount of free quotas under this allocation rule as \bar{s}_1 and \bar{s}_2 . The amounts of free quotas allocated for period 2 is a fixed amount, known with certainty in period 1. Hence \bar{s}_2 is independent of the outcome of p_2 . This means that the firm's expected amount of \bar{s}_2 allocated in period 2, denoted $E\bar{s}_2$, is fixed and also that it is known in period 1.

3.4 The order of the play

The model described in section 2 above can be understood as a game between the regulator and the firm. The order of the play in this game is as follows:

1. At the beginning of period 1, the regulator announces the allocation of quotas for period 1 and which of the allocation rules, described above, that will be followed for period 2.

2. With this information available in period 1, the firm then decides whether or not to invest in T^V and whether or not to continue to produce in that period. The firm will choose to invest if (9) is satisfied and the firm will choose to maintain production if

$$D_1(s_1, T^j) \geq 0 \quad \text{where } j \in \theta, V \quad (12)$$

Let $s_1^{D_1}(p_1, T)$ denote the required amount of s_1 that fulfills equation (12) with equality. Further let $s_1^1 \equiv s_1^{D_1}(p_1, T^0)$, $s_1^2 \equiv s_1^{D_1}(p_1, T^V)$

3. At the beginning of period 2, p_2 is observed, and under the flexible and the semi-flexible options, the regulator announces the amount of s_2 that will be allocated to the firm in that period.
4. On the basis of this information, the firm decides whether to continue production in period 2. The firm will produce in period 2 if

$$D_2(s_2, T^j) \geq 0 \quad \text{where } j \in \theta, V \quad (14)$$

Let $s_2^{D_2}(p_2, T)$ denote the required amount of s_2 that fulfills equation (14) with equality. Further let $s_2^1 \equiv s_2^{D_2}(p_2^L, T^0)$, $s_2^2 \equiv s_2^{D_2}(p_2^H, T^0)$, $s_2^3 \equiv s_2^{D_2}(p_2^L, T^V)$, $s_2^4 \equiv s_2^{D_2}(p_2^H, T^V)$, $s_2^1 > s_2^2$ and $s_2^3 > s_2^4$

Equations (12) and (14) are henceforth referred to as the production constraints.

Given this game, a regulator that wants to secure production in both periods will seek to minimize the total amount of free quotas necessary for firm survival because of the social costs of public funds. This implies that, given production in both periods, the regulator must ensure that the firm chooses to use the cost-minimizing technology.

4 The impact of different allocation rules when investment in abatement technology is not cost-minimizing

In the following we consider the situation where the investment in T^V is not cost minimizing even with production in both periods. Hence equation (8) will not be fulfilled, and in this case, the regulator prefers that the investment not be implemented. This implies that the production constraints given by equations (12) and (14) have to be satisfied given the use of technology T^0 . The regulator will only allocate the minimum amount of quotas necessary to achieve its goal, which implies that in period 1 it has to minimize $(s_1 + Es_2)$ given that (12) and (14) are satisfied.

4.1 The flexible and semi-flexible options

Under the flexible and semi-flexible options, the minimum amount of quotas that the regulator has to allocate to the firm in period 1 is given when equation (12) given T^0 is satisfied with equality. However, in period 2 under the flexible option, the firm anticipates that when the regulator wants to ensure production it will choose a s_2 that minimizes the cost of doing this, defined in equation (15) given T^0 . The outcome of s_2 is thus the same as it is under the semi-flexible option when the regulator seeks to minimize the amount of s_2 paid given that (14) is satisfied for both outcomes of p_2 . The expected amount of s_2 allocated to the firm under the flexible and the semi-flexible options is hence

$$E\hat{s}_2 = E\tilde{s}_2 = (1 - \gamma)s_2^l + \gamma s_2^2 \tag{16}$$

4.2 The fixed option

Under this option, the regulator announces the amount of quotas allocated to the firm for both periods during period 1, and the amounts allocated in both periods are known with certainty to the firm. The minimum amounts of s_1 and s_2 that the regulator has to allocate to the firm in period 1 and period 2 to ensure production in these periods are given when the production constraints given by equations (12) and (14) given T^0 are satisfied with equality. The amount of s_1 allocated is the same amount that is allocated to the firm under the flexible and the semi-flexible option.

With uncertainty of p_2 and when the regulator wants to ensure production for both outcomes of p_2 , the regulator has to pay the level of subsidies that leaves the firm with a short-term non-negative profit in period 2, even if p_2 is low. Hence, $E\bar{s}_2 = s_2^l$. Without the possibility of taking into account the new information made available in period 2 about p_2 , subsidies must be paid such that if the worst case is realized, production is still profitable. The expected amount of s_2 allocated under the fixed option ($E\bar{s}_2$) is hence higher than the expected amount allocated under the flexible and the semi-flexible options (given by equation (16)).

The flexible and semi-flexible options will reduce the regulators' expected costs of ensuring production in both periods compared to the fixed option when investment in T^V is not cost minimizing

5 Impact of different allocation rules when the investment in abatement technology is cost minimizing

We now consider a situation where the regulator wants to secure production in both periods, both at a high and a low level of p_2 and where T^V is the cost-minimizing technology given that the firm produces in both periods, that is, that (8) is satisfied. This implies that the regulator must ensure that the expected total long-run profit from investing in T^V is as profitable as the expected total long-run profit from keeping the old technology T^0 . To secure production in both periods for both outcomes of p_2 given that the firm has invested in T^V , the amount of s_1 and s_2 allocated to the firm must fulfill the production constraint given by conditions (12) and (14) given T^V . If the production constraints (12) and (14) are satisfied for T^V the production pair $\{x_1, x_2\}$ that maximizes $\Pi(T^V, x_1, x_2)$ is $\{1, 1\}$. When (8) is satisfied, it is profitable for the firm to invest if it produces in both periods, that is, $\Pi(T^V, \{1, 1\}) \geq \Pi(T^0, \{1, 1\})$. However, even though (8) is satisfied, it may be more profitable to keep the old technology and only produce in period 1, or to close down production, than to invest and produce in both periods. Hence, if the regulator ensures that (12) and (14) are satisfied, the expected total long-run profit from production in both periods with T^V , is as profitable as the maximum expected total long-run profit from keeping the old technology, T^0 if

$$E[\Pi(T^V, 1, 1) - \text{Max}\{\Pi(T^0, 1, 0), \Pi(T^0, 0, 0)\}] \geq 0 \quad (17)$$

We henceforth refer to (17) as the investment-constraint.

The regulator minimizes the amount of free quotas given to the firm contingent on production at the capacity level (s, Es) given that (12), (14), and (17) are satisfied.

The amount of s_1 determines whether it is most profitable for a firm that has not invested to produce in period 1 and close down in period 2, or to close down in period 1 (and hence receive zero profit). If (12) and (14) are satisfied and the amount of free quotas for period 1 (s_1) is given by

$$s_1 < s_1^2 + t[U(T^0) - U(T^V)], \quad (18)$$

the investment constraint is given by

$$E[\Pi(T^V, 1, 1)] \geq \Pi(T^0, 0, 0), \quad \text{where } \Pi(T^0, 0, 0) \equiv 0 \quad (19)$$

If (12) and (14) are satisfied and the amount of free quotas for period 1 (s_1) is given by

$$s_1 \geq s_1^2 + t[U(T^0) - U(T^V)], \quad (20)$$

the investment constraint is given by

$$E[\Pi(T^V, 1, 1)] \geq \Pi(T^0, 1, 0), \quad \text{where } \Pi(T^0, 1, 0) \geq 0 \quad (21)$$

It can be seen from (22) and (11) that the firms expected profit must be positive in order to ensure investment if s_1 satisfies (20) with inequality. However, if s_1 is given by (18), the firm can be left with zero profit in order to ensure investment (if (12) and (14) are satisfied). Hence, it is never optimal for the regulator to choose an amount of s_1 that satisfies (20) with inequality. We will therefor in the following concentrate on the situation where s_1 is given by (18) and the investment constraint is given by (19). (If s_1 satisfies (20) with equality, the profit of producing in only period 1 equals zero and hence equals the profit of closing down production in period 1, that is, $\Pi(T^0, 1, 0) = \Pi(T^0, 0, 0)$). It should be noted that if s_1 satisfies (20), an increase in s_1 increases the profit of non-investment with an equal amount.

5.1 The flexible option

In the flexible option, the regulator has not made any commitments regarding the allocation of free quotas in period 2. However, we have assumed that the regulator wants the firm to produce in both periods for both outcomes of p_2 . We also assume that the regulator wants to ensure production in both periods even if the firm has not invested, and that the firm knows this.⁷ The regulator observes the emissions in period 1 and can therefore deduce whether the firm has implemented the investment or not. The firm will anticipate that the amount of quotas received in period 2 will be sufficient to ensure profitable production. However, since the regulator seeks to minimize the total amount of quotas allocated, the firm correctly anticipates that the regulator chooses the minimum amount of quotas that ensures profitable production. Hence $E\tilde{s}_2 = s_2^{D_2}(p_2, T^j)$ where $s_2^{D_2}(p_2, T^j)$ is defined in (15). The firm's profit in period 2 will then equal zero, hence $\Pi(T^j, \{1, 0\}) = \Pi(T^j, \{1, 1\})$.⁸

If the amount of quotas allocated in period 1 (\tilde{s}_1) satisfies (18) and $E\tilde{s}_2 = s_2^{D_2}(p_2, T^j)$, it can be seen from (10) and (11) that the investment constraint (17) is satisfied only if

$$qT^V \leq [t_1 U(T^0) - t_1 U(T^V)] \quad (22)$$

The above equation is not satisfied by assumption (see eq.(7)).

In this paper, we consider a situation where the regulator is incapable of forcing the firm to produce in both periods or to implement the investment in T^V . The regulator uses free quotas as the only mean to induce the firm to produce and implement the cost-minimizing investment. The quotas allocated to the firm in each period can be thought of as consisting of two parts. One part ensures profitable short-run production in each period, and the other covers a share of the investment cost. Hence, the investment cost can be partly covered through the free quotas in period 1 and partly covered by the free quotas in period 2. When the regulator has no binding commitments regarding the free quotas allocated in period 2, it is optimal for the regulator at the

⁷ This assumption does not affect the conclusions (see footnote 8) since the firm's expected profit in period 2 equals zero, whether it has invested or not.

⁸ Since the firm's expected profit in period 2 equals zero whether it has invested or not, the firm's investment decision is independent of whether the regulator wants to ensure production. The firm's profit in period 2 cannot be less than zero even if the regulator does not want to ensure production since the profit of closing down production also equals zero.

beginning of period 2 to not allocate a larger amount of quotas than the amount necessary to ensure zero short-run profit in that period. Therefore, the amount of free quotas in period 2 does not cover any part of the investment cost. As long as s_1 satisfies (18) the total amount of quotas over both periods is not sufficient to ensure that the profit of investment is non-negative. The expected profit of investment is zero if s_1 covers the entire investment cost in addition to ensuring zero short run profit. However, that will imply that s_1 satisfies (20) with inequality and the maximum profit of non-investment will be positive and larger than the profit of investment. An increase in s_1 will not ensure investment since the profit of non-investment will increase by the same amount (as discussed in the previous section). This leads to the following conclusion:

If the regulator does not make any commitments regarding the free quotas distributed in period 2, the firm will never implement the investment. The firm will correctly anticipate that the free quotas distributed in period 2 will only cover the short-run profit and not any of the investment cost. The regulator cannot induce the firm to invest by distributing free quotas in period 1 sufficiently to ensure that the expected profit of investment is non-negative, since this will make it more profitable to not invest and produce only in period 1.

5.2 The semi-flexible option

In contrast to the flexible option, the semi-flexible option implies that the regulator has made commitments in period 1 regarding the allocation of quotas in period 2. We will in the following consider whether, and under what conditions, this system can induce the firm to invest in T^V and produce in both periods.

As discussed above, the regulator will seek to minimize the necessary total amount of free quotas allocated to the firm (\hat{s}_1 and $\hat{s}_2(p_2)$) to ensure production in both periods and investment in T^V . The minimum value of \hat{s}_1 , which ensures production in period 1 given that the firm has invested in T^V , is s_1^2 , defined in (13).

The minimum values of $\hat{s}_2(p_2)$ that ensure production in period 2 for both outcomes of p_2 given that the firm has invested in T^V is s_2^3 if $p_2 = p_2^L$ and s_2^4 if $p_2 = p_2^H$ (s_2^3 and s_2^4 are defined in (15)).

As discussed in the previous section, s_1 given by (20) will only make the profit of non-investment positive and hence increase the regulator's cost of ensuring investment. We will hence in the following only consider the situation where \hat{s}_1 satisfies (12) and (18), and the investment constraint is hence given by (19).

When (12) and (18) is satisfied, \hat{s}_1 is given by

$$\hat{s}_1 = s_1^2 + \alpha \cdot t_1 [U(T^0) - U(T^V)] \quad 0 \leq \alpha < 1$$

where $t_1(U(T^0) - U(T^V))$ is the emission costs following from using technology T^0 instead of T^V . As long as the regulator sets $\alpha < 1$, these extra emission costs will not be fully covered by the allocation of free quotas in period 1. Hence, it will never be profitable for the firm to produce without investing in T^V .

In order to find the minimum amount of $(\hat{s}_1 + E[\hat{s}_2(p_2)])$ that ensures that (17), (12) and (14) are satisfied, we find the amounts of $\hat{s}_2(p_2^H)$ and $\hat{s}_2(p_2^L)$ that ensure that (19) is

satisfied with equality, given that \hat{s}_1 satisfies (12) and (18), and later check whether this solution also ensures that (14) is satisfied.

It can be seen from (10) (which defines the long-run profit for the firm over both periods with T^V) that when the firm produces in both periods, (19) is satisfied with equality if

$$\begin{aligned} \hat{s}_1 + \gamma \hat{s}_2(p_2^H) + (1 - \gamma) \hat{s}_2(p_2^L) = \\ - [p_1 - c_1 - t_1 U(T^V)] - [\gamma p_2^H + (1 - \gamma) p_2^L] - c_2 - t_2 U(T^V) + qT^V \end{aligned} \quad (23)$$

Inserting for s_1^2 , s_2^3 and s_2^4 into (23) leads to the following solution for the expected amount of quotas that leads to zero expected profit of investment in T^V :

$$\hat{s}_1 + E[\hat{s}_2(p_2)] = \hat{s}_1 + \gamma \hat{s}_2(p_2^H) + (1 - \gamma) \hat{s}_2(p_2^L) = s_1^2 + \gamma s_2^4 + (1 - \gamma) s_2^3 + qT^V$$

Let \hat{s}'_1 , $\hat{s}'_2(p_2^H)$ and $\hat{s}'_2(p_2^L)$ denote the amounts of free quotas that minimize the total expected amount of quotas allocated to the firm ($\hat{s}_1 + E[\hat{s}_2(p_2)]$) given that \hat{s}'_1 satisfies (12) and (18).

$$\begin{aligned} \hat{s}'_1 &= s_1^2 + \alpha \cdot t_1 [U(T^0) - U(T^V)] \\ \hat{s}'_2(p_2^L) &= s_2^3 - \alpha \cdot t_1 [U(T^0) - U(T^V)] + qT^V \\ \hat{s}'_2(p_2^H) &= s_2^4 - \alpha \cdot t_1 [U(T^0) - U(T^V)] + qT^V, \quad 0 \leq \alpha < 1 \end{aligned} \quad (24)$$

It can be seen from (24) and (7) that $\hat{s}'_2(p_2^H) > s_2^4$ and $\hat{s}'_2(p_2^L) > s_2^3$. (The production restriction given by (14) is hence satisfied). This leads to the following conclusion:

The regulator's commitments regarding the allocation of free quotas for period 2 under the semi-flexible option must give the firm an expected positive short-run profit in period 2 when the regulator wants to ensure investment. The expected short-run profit, given that the firm has invested, must be positive and larger (or equal) to the investment cost minus the cost savings of the investment in period 1 in order to make it more profitable for the firm to invest than to keep the old technology.

Note that under the flexible option discussed in the previous section, the firm did not invest since the expected short-run profit in period 2 equaled zero.

Furthermore, since the amount of quotas characterized by (24) is found by setting $E[\Pi(T^V, 1, 1)] = 0$, we can conclude the following:

The fact that the firm has the possibility of achieving free quotas in period 1 and closing down in period 2 does not increase the regulator's cost of ensuring investment and production in both periods. Hence, the minimum total amount of quotas that ensure that the expected profit of the investment is non-negative is sufficient to ensure that the firm implements the investment, but demands a certain distribution of quotas over time. The share of the free quotas that are allocated in period 1 must not be too large compared to the share allocated in period 2.

5.3 The fixed option

As for the semi-flexible allocation rule, the fixed allocation rule implies that the regulator has made commitments in period 1 regarding the allocation of quotas in period 2. The allocation of quotas for period 2 is a fixed amount independent of the outcome of p_2 and observed emissions, but allocated contingent on continued production.

As with the other allocation rules, the regulator will seek to minimize the necessary total amount of free quotas allocated to the firm (\bar{s}_1 and \bar{s}_2) to ensure production in both periods and investment in T^V . The minimum value of \bar{s}_1 , that ensures production in period 1 given that the firm has invested in T^V , is s_1^2 , defined in (13).

The minimum value of \bar{s}_2 , that ensures production in period 2 for both outcomes of p_2 given that the firm has invested in T^V , and hence ensures that (14) is satisfied for $T=T^V$, is s_2^3 , defined in (15).

In order to find the regulator's optimal choice of \bar{s}_1 and \bar{s}_2 , we find the amount of \bar{s}_2 that gives $E[II(T^V, I, I)] = 0$, given that \bar{s}_1 satisfies (12) and (18) and later check whether the solution to \bar{s}_2 satisfies (14). This leads to the following

$$\begin{aligned}\bar{s}'_1 &= s_1^2 + \alpha \cdot t_1 [U(T^0) - U(T^V)] \\ \bar{s}'_2 &= s_2^3 + qT^V - \alpha \cdot t_1 [U(T^0) - U(T^V)] - \gamma(p_2^H - p_2^L), \quad 0 \leq \alpha < 1\end{aligned}\tag{25}$$

where \bar{s}'_1 and \bar{s}'_2 denote the amounts of free quotas that minimize the total expected amount of quotas allocated to the firm ($\bar{s}_1 + E[\bar{s}_2]$) given that \bar{s}'_1 satisfies (12) and (18).

The production constraint (14) is satisfied for both outcomes of p_2 if $\bar{s}_2 \geq s_2^3$. Let B denote the term $[qT^V - \gamma(p_2^H - p_2^L)]$. When $B \geq 0$, there exists an α , $0 \leq \alpha < 1$, that implies that equations (14) and (25) can be satisfied. However, when $B < 0$, (14) will not be satisfied for any α , $0 \leq \alpha < 1$, when \bar{s}'_2 is given by equation (25). Hence, in the following we will examine the solution for \bar{s}'_1 and \bar{s}'_2 , depending on whether B is negative or non-negative.

5.3.1 B is non-negative $[qT^V \geq \gamma(p_2^H - p_2^L)]$

When $B \geq 0$, the minimum amount of \bar{s}_1 and \bar{s}_2 that ensures that (17), (12) and (14), are satisfied, denoted \bar{s}_1^* and \bar{s}_2^* , are given by

$$\begin{aligned}\bar{s}_1^* &= s_1^2 + \alpha \cdot t_1 [U(T^0) - U(T^V)] \\ \bar{s}_2^* &= s_2^3 + qT^V - \alpha \cdot t_1 [U(T^0) - U(T^V)] - \gamma(p_2^H - p_2^L), \\ \text{and} \\ 0 \leq \alpha &< \text{Min}\left\{1, \frac{[qT^V - \gamma(p_2^H - p_2^L)]}{t_1 [U(T^0) - U(T^V)]}\right\}\end{aligned}\tag{26}$$

The solution to \bar{s}_1^* and \bar{s}_2^* given by (26) satisfies the production constraints and ensures that the expected long-run profit of the investment in T^V is zero. When $B \geq 0$, we get the same conclusion as under the semi-flexible system:

The minimum total amount of quotas that ensure that the expected profit of the investment is non-negative is sufficient to ensure that the firm implements the investment, but demands a certain distribution of quotas over time.

We concluded in section 3 that when the investment is not cost-effective, the semi-flexible system is less costly than the fixed system. However, when the investment in T^V is cost minimizing, this conclusion no longer holds when $B \geq 0$.

The fact that the amount of free quotas for period 2 is fixed in period 1 and independent of the outcome of p_2 does not necessarily increase the regulator's cost compared to a situation where the amount of quotas for period 2 is a function of the outcome of p_2 . Both allocation rules may leave the firm with zero expected long-run profit and hence lead to the same expected minimum amount of quotas necessary to ensure investment and production in both periods.

It should be noted that even though the two different allocation rules leave the firm with identical *expected* profit, the realized profit will differ. The fixed option implies that the firm will have a positive profit if the outcome of p_2 is p_2^H , whereas the profit will be negative if the outcome is p_2^L . The semi-flexible allocation option ensures that the firm's profit is zero for both outcomes of p_2 . We have in this paper considered a risk-neutral firm. However, if the firm in question is risk averse, it will demand a risk premium in order to invest under the fixed option. In that case, the firm's expected profit must be positive under the fixed option in order to induce the firm to invest.

5.3.2 B is negative ($qT^V < \gamma(p_2^H - p_2^L)$)

With $B < 0$, we see that \bar{s}_1' and \bar{s}_2' given by (26) are not sufficient to satisfy (14) for any α , $0 \leq \alpha < 1$. Hence, the amount of free quotas that is sufficient to ensure that the expected profit of the investment is positive, is not sufficient to ensure that the firm produces in both periods. In this case, the production constraints (14) will be the binding constraints.

When $B < 0$, the minimum amount of \bar{s}_1 and \bar{s}_2 that ensures that (17), (12) and (14), are satisfied, denoted \bar{s}_1^* and \bar{s}_2^* , are given by

$$\begin{aligned}\bar{s}_1^* &= s_1^2 \\ \bar{s}_2^* &= s_2^3\end{aligned}\tag{27}$$

where s_1^2 and s_2^3 are defined in equation (13) and (15). The expected profit of the investment is greater than zero, and the firm will get a positive expected profit equal to $-B$. (Observe that \bar{s}_1^* and \bar{s}_2^* given by (27) satisfy the investment constraint given by (17)).

The fixed amount of quotas allocated in period 2 (\bar{s}_2) must be sufficient to ensure production also for a low level of p_2 . When $B < 0$, the amount of quotas that ensure profitable production in period 2 more than offsets the minimum amount of quotas that ensure that the investment in T^V is cost minimizing. Hence, as in the case where the investment is not cost minimizing, (discussed in section 4), the lack of the possibility for taking into account new information about p_2 increases the regulator's cost.

It follows from the definition of B and the discussion above that:

The smaller investment cost, the higher probability for p_2^H , and the larger the range for the possible outcomes of p_2 , the higher the probability is that the fixed system will be more costly than the semi-flexible system.

6 Concluding remarks

In this paper we have considered a situation where a country has signed an international agreement to reduce emissions of climate gases. Their obligations are met by implementing a national tradable quota system. The question analyzed is how to design the tradable quota system when the regulator in the country we are considering is concerned about the survival of specific firms. The problem is studied within a two-period model to be able to include the effects of a chosen design of the tradable quota system on the firm's decision to invest in abatement technology.

To ensure survival of specific firms over the two periods, quotas are allocated for free on a firm-specific basis. We consider a situation where the output price of the firm's product in period 2 is uncertain. The period 2 price is assumed to be either high or low with a certain probability distribution. Three different tradable quota systems are studied in the paper:

- The flexible option, where it is only the amount of free quotas allocated in period 1 that is known to the firm.
- The semi-flexible option, where the amounts of free quotas allocated in period 2 is a function of the price level in that period, and that this function is known to the firm in period 1. The firm also knows the amount of free quotas allocated for period 1 with certainty.
- The fixed option, where the firm knows the amounts of free quotas allocated in the two periods with certainty in the first period.

We assume that the regulator wants to secure the firm's production in both periods. Further, we compare the different systems under assumptions of whether an investment in abatement technology that can be made by the firm is cost minimizing or not. We show that

- when the investment in abatement technology is not cost minimizing, all allocation rules fulfill the regulator's preferences about production and investment decisions. However, when the investment in new technology is cost minimizing, the flexible option will, within the model studied here, lead to a situation where the investment in abatement technology is not undertaken. The reason for this is that the firm expects that it will receive quotas in period 2 that will only cover production costs, and not any of the investment costs. It is not possible to allocate the total required amount of free quotas in period 1 because of the risk that the firm will take the subsidy and choose not to invest.
- when it comes to ranking the various allocation rules with respect to the total amount of free quotas allotted to an agent, there is a difference between a situation where the investment in abatement technology is cost minimizing and when it is not. When the investment is not cost minimizing, the flexible and semi-flexible options reduce the regulator's expected costs of fulfilling its preferences about production and investment decisions compared to the fixed option. When the investment in new technology is cost minimizing, the total expected costs of fulfilling the regulator's preferences about production and investment decisions under the fixed and semi-flexible options may under certain conditions be equal. However, it is more likely that the semi-flexible option leads to lower expected costs than the fixed option; the lower the investment costs are, the higher

the difference between the two outcomes of the stochastic period 2 price, and the higher the possibility of a high period 2 price.

In this paper we have assumed that the regulator demands only that the firm continue production in order to receive the free quotas. However, if the regulator also can make demands on investment in T^V before it distributes the free quotas, investment will be ensured. A justification for our assumption is, first, that it may not be politically feasible to interfere with the firm's choice of technology, and second, that the firm's investment may not be observable for the regulator.

When the regulator cannot/does not allocate quotas contingent on investment, a credibility problem with the fixed and semi-flexible options may arise when the investment in abatement technology is cost minimizing. If there is a credibility problem, the same situation as under the flexible system may occur. If the regulator does not pay all the subsidies necessary to make the firm invest in T^V and continue production in period 1, the firm will believe that in period 2 the regulator will minimize the necessary subsidies paid to get the firm to produce in that period given the investment decision made in period 1. This implies that both under the fixed and semi-flexible options it will believe that when period 2 arrives, the subsidies paid under the flexible option will be realized, and as a result no investments in T^V will be made. As shown in the paper however, the problem cannot be resolved by subsidizing the total required amount of free quotas to make the firm produce and invest in T^V in period 1, for the reason discussed above. By doing so, the regulator runs the risk that the firm will take the subsidy and choose to not invest.

The problem analyzed in this paper is discussed within a finite time horizon divided into two periods. However, the results obtained would not change if we introduced more than two periods. The free quotas must still be allocated so that production is secured in each period and that the investment is made in period 1.

7 References

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