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The merits of non-tradable quotas as a domestic policy instrument to prevent firm closure*

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1 Introduction

The starting point of this paper is that the government in a specific country has signed an international agreement (the Kyoto Protocol) to reduce emissions of climate gases and has decided to establish a domestic quota trading system to meet its obligations. It is assumed that an international system of tradable quotas has been established and that the domestic firms can trade quotas directly on the international market.[1] There is a concern in many countries that a domestic tradable quota system, where all emitters must pay for their quotas, may lead to closures of emissions-intensive industrial companies. For some firms, the increased costs resulting from 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 such a move 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 without emissions obligations under the Kyoto Protocol. (This is often referred to as the carbon-leakage problem).[2] 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.[3]

Allocating quotas free of charge to companies operating in competitive markets has been suggested/used as a means to reduce the likelihood of closures following from a domestic tradable quota system in several countries.[4] The Canadian Tradable Permits Working Group envisages in their report (TPWG 2000) a framework for allocation of quotas that is *inter alia* composed of a continued free allocation of permits to producers competing with non-Annex B signatories to the Kyoto Protocol (developing countries)[5]. In Denmark, electricity producers receive annual emissions permits for CO_2. The Norwegian "Quota Commission" was appointed by the government in 1998 to draw up a domestic quota trading system for greenhouse gases based on the Kyoto Protocol. (See The Quota Commission, 2000). In accordance with its mandate, the Commission discussed allocating free quotas to industrial companies that would cover a certain percentage of their total emissions at 1990 levels.

According to the Coase Theorem, the initial allocation of legal entitlements does not matter from an efficiency perspective as long as they can be exchanged in a perfectly competitive market and there are no transaction costs. See Coase (1960). Unconditional initial allocation of quotas hence does

[1] This assumption is not crucial for the conclusions in this paper. The same conclusions would be reached if only a domestic tradable quota system was established.

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

[3] Another reason for implementing policies to prevent firm closures or the firm from moving production to other countries is imperfect output markets. Such strategic environmental policies is *inter alia* discussed in Markusen et al (1993 and 1995) and Hoel (1997), but ignored in this paper.

[4] In the discussion about the merits of distributing free quotas at a domestic level, it is normally assumed that the quotas are allocated on a general basis, for instance by allocating quotas to firms based on historical emissions (grandfathering). This is also assumed in this paper. However, it should be noted that if the regulator wants to minimize the cost of securing survival of firms, the allocation of free quotas to each firm should be set equal to the minimum number of quotas necessary to ensure non-negative profit of that firm, and not on historical emissions. Such allocation policy is *inter alia* studied in Hagem and Westskog (2000), Jebjerg and Lando (1997) and Hagem (2001b).

[5] The Tradable Permits Working Group was established under Canada's National Climate Change Process in 1998.

not affect the firms' production and abatement decisions if the quotas can be traded in a competitive market. And consequently, allocating quotas free of charge will not prevent a firm from closing down if closure would be the most profitable option in a system where the firm had to purchase quotas. The initial allocation does, however, affect the distribution of wealth.

If the purpose of allocating free quotas is to prevent shutdowns, the regulator can put some restrictions on the sale of quotas or make the allocation conditional on the firms' production. (This is *inter alia* discussed in Hagem (2001a)). Conditional allocation implies, for example, that the allocation of quotas is based on historic emissions and is contingent on avoiding closure of the firms concerned or maintaining minimum production. Another possibility is to allocate quotas proportional to the current level of production within the firm. There are, however, several practical problems regarding how to define and calculate production levels. The firms may change the composition of commodities produced over time, or they may start to produce other items. Furthermore, if the allocation of quotas is based on a certain minimum level of production, some companies may find it profitable to reduce the production to the minimum level and sell their excess amount of free quotas.

Conditional allocation of tradable quotas may lead to high administration costs because the regulator needs access to information about production levels, and it will be necessary to evaluate whether the firms fulfil the requirements for receiving quotas and, if so, how many quotas the firms are entitled to receive. These evaluations have to be based on the regulators information about the firms' production. As long as allocation of quotas is based on the regulator's judgement of current production data, firms have the incentive to manipulate production data and lobby for their interests.

Due to the possible high administration cost, the incentive to lobby, and inefficiencies resulting from the problems of conditional allocation of tradable quotas, the majority of the Norwegian Quota Commission concludes that if any quotas are allocated free of charge to some firms in order to moderate or postpone restructuring or closures, these quotas should be allocated as non-tradable quotas. The Commission further proposes that the allocation to each firm be set proportional to the firm's historic emissions.

This paper looks at two different designs of free quotas systems within a two period model: one where the quotas given free of charge are tradable, and one where the quotas are non-tradable. Surplus quotas from the first period can be banked to the second period in which the firms no longer receive free quotas. The focus of the paper is the impact of the two different designs of quota systems on the firms' investment decisions and hence their competitiveness in the future when they no longer receive free quotas. The difference in transaction cost between the two systems is ignored.

A commonly given argument against non-tradable quotas is that firms will have less incentive to abate than under tradable quotas. However, it is shown here that if quotas are allocated free of charge for a limited number of years only, and can be banked, this argument no longer necessarily holds if the firm holds a larger amount of non-tradable quotas than its emissions in the first period. The larger amount of free quotas the firms receive, the more likely is it that firms undertake abatement investment under the non-tradable quota system. The firms' decisions regarding investment in abatement technology in the first period have an impact on their competitiveness also in the second period.

The next section presents the general model where the firm's production and investment decisions are derived under the different systems for free quotas. Section three compares the two different systems with respect to their ability to both induce firms to invest in new abatement technologies and prevent firms from closing down production. Concluding remarks are given in the last section.

2 The model

Two different designs of free quotas systems are studied: The quotas allocated free of charge, denoted *Q*, can either be tradable or non-tradable. If the quotas are tradable, the system is referred to as a "tradable-quota system." Similarly, a system with non-tradable free quotas is referred to as a "non-tradable quota system."

A two-period model is used where the first period could be considered as the Kyoto period (2008–2012) or several successive "Kyoto periods". Under both systems, domestic emissions-intensive firms operating in competitive markets receive quotas free of charge, proportional to their historical emissions, in the first period. The tradable quotas are allocated contingent on continued production. It is assumed that the firms are allowed to buy additional quotas on the quota market under both quota systems. Surplus quotas from the first period can be banked to the second period. Furthermore, it is assumed that the emissions-intensive firms do not receive quotas free of charge in the second period.[6] All other domestic emitters must meet their quota requirements in both periods through purchase on the international quota market. The government sells its initial allocation of quotas on the international quota market, except for the quotas allocated free of charge to emissions-intensive firms.[7]

In order to study the impact on the firms' abatement and production decisions, it is considered the way one specific firm responds, depending on its emissions, possibilities for abatement and future competitiveness. By considering how the specific firm responds to the different systems, it can be derived how the two different systems for allocation of free quotas in general influence firms' abatement and production decisions depending on firm's abatement costs, emissions and expectations about future prices for the good they produce.

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.[8] The annual capacity output is normalized to 1.

Although the production capacity is fixed, it is assumed that a firm may reduce the emissions per unit through a specific investment in abatement technology.[9] There are hence two possible outcomes for the firm's annual emission levels in the two periods, denoted E^i, if the firm produces

$$E = E^i \qquad i = 0, N \tag{1}$$

where annual emissions resulting from production prior to investment in new abatement technology is denoted E^0, and annual emissions following from the investment in new abatement technology is denoted E^N.

[6] The reason for this assumption is either because international trade regulations may allow subsidization of production through free quotas only for a limited number of years as an interim arrangement, or because it is politically unacceptable to subsidize production for an infinite number of years.

[7] The government's total number of quotas follows from the quantified emissions limitations under the Kyoto Protocol.

[8] Emissions-intensive industries include manufacturing of metals, where a feature of the production process is 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 full capacity, or to permanently or temporarily close down production.

[9] The impact of abatement possibilities that do not include investment costs but increase production costs is discussed in the final section.

Since the firm's decision to invest in new abatement technology is considered here, the lifetime of the firm's production plant has to be taken into account. The lifetime of the production plant is *n* years. In the first period, which lasts Y_1-years, the firms receive quotas free of charge. The second period, consisting of Y_2 years, is the remaining lifetime of the production plant, that is $Y_2 \equiv n - Y_1$. Obviously, the length of the two periods will generally differ. If the differences in the length of the two periods are very large, some of the assumptions made here will be difficult to justify. The implications of large differences in the number of years within each period are discussed in the last section.

The price of the good produced in period 1 is known at the beginning of period 1, but the price in period 2 is uncertain[10].

It is assumed that the investment cost is higher than the reduction in emissions cost, defined as quota price (*t*) multiplied by emissions reduction, in one of the periods, but lower than the total reduction in emissions cost over both periods.

$$I^N > t_j \cdot \left[E^0 - E^N\right] Y_j \qquad j = 1,2$$
$$and \qquad (2)$$
$$I^N \le t_1 \cdot \left[E^0 - E^N\right] Y_1 + t_2 \cdot \left[E^0 - E^N\right] Y_2$$

where I^N is the sunk cost of investment.

Hence, in a situation where the emitter has to pay for the quotas, the investment in new abatement technology is profitable if the firm finds it profitable to produce in both periods, but not if the firm produces with the new technology only in one period.

To simplify the presentation, it is assumed that all prices within each period increase in accordance with the rate of interest, and that the present value of the quota price *t* remains the same in both periods.[11,12] Furthermore, any production costs other than those associated with the cost of buying emission quotas are disregarded. If the firm had to cover it needs for quotas by purchasing all quotas on the market, the firm's annual income is given by

$$\pi_j = p_j - tE^i \qquad j = 1,2 \quad and \quad i = N,O \qquad (3)$$

The focus in this paper is how differences in the design of free quota systems influence the firms' competitiveness and hence production decisions in the future when the firm no longer receives free quotas. A situation where it is always profitable for the firm to produce in the first period when it receives quotas free of charge is considered. In order to make the two systems comparable, the number of free quotas distributed to the firm is identical under the two different designs of free quota systems, which means that no non-tradable quotas are unused and hence redistributed back from the firm to the

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[10] After the first Kyoto period, more countries may participate in the agreements and countries that have previously distributed free quotas may choose to end the subsidization policy and let all domestic emitters face the same quota price. The future prices of the internationally traded goods produced by emissions-intensive industries are therefore considered to be uncertain and dependent on the development of the international climate regime and how countries choose to meet their obligations. The more countries participating in the climate agreement choose to subsidize their industries that are in danger of being closed down or moved to another country, the lower p_2.

[11] As long as quotas are tradable and bankable (as in the Kyoto Protocol) and the cost of emissions reduction increases over time (for instance due to lower emissions limitations), the *expected* quota price will be equalized across periods.

[12] An uncertain t_2 will have the same qualitative effects as an uncertain p_2.

regulator. If that were not the case, the two different systems could incur uneven costs for the regulator because of the differences in total allocation of free quotas.

The next two subsections derive the firm's investment decision in the first period and production decision in the second period when the free quotas are tradable and when they are non-tradable.

2.1 Tradable quotas

This section derives the firm's income from production (short-run profit) in each period and the conditions for continued production in the second period.

A firm that produces in first period receives *Q* quotas during that period. With a quota price of *t* and fully tradable quotas, the value of these quotas equals $t \cdot Q$. A profit-maximizing firm will continue to produce in the second period as long as the annual income from production, denoted π_2^{TQ}, is positive. Production will continue if the following condition is satisfied;

$$\pi_2^{TQ} = p_2 - tE^i \geq 0 \qquad i = N,O \tag{4}$$

If (4) is not satisfied, the firm will close down. Since the present value of p_2 and t is assumed to be constant within the second period, a profit-maximizing firm either continues production throughout the entire second period or it closes down production.

It is assumed that it is profitable for the firm to produce in period 1 when it receives quotas free of charge contingent on continued production, and that the annual capacity output is normalized to 1. Let x_2 denote the firm's total production in period 2. Since the annual capacity output is normalized to 1, and period 2 consists of Y_2 years, we get

$$x_2 \in \{0, Y_2\} \tag{5}$$

The income in period 1 and period 2 are both functions of the investment decision in period 1, while the amount of free quotas only has an impact on the income in period 1.[13]

Let D_j^{TQ} denote the total short-run profit in period *j* if it produces in period *j* (*j=1,2*).

$$D_1^{TQ}(Q, E^i) = Y_1\left[p_1 - tE^i\right] + tQ \quad i = 0,N \tag{6}$$

$$D_2^{TQ}(p_2, E^i) = Y_2\left[p_2 - tE^i\right] \quad i = 0,N \tag{7}$$

We see from (7) that the total short-run profit in period 2 is larger if the firm has invested in period 1 than if it has not. This means that it is more likely that the firm will continue production in period 2 if it has invested in new abatement technology in period 1. The firm's investment decision in period 1 thus influences the firm's production decision in period 2. In order to evaluate the impact on production of the free quotas, we must derive the impact on the firm's investment decisions. It is assumed that the firm is risk neutral so it invests in period 1 if, and only if, the expected increase in profit from investing is positive. Let $\Pi^{TQ}(E^0, x_2)$ and $\Pi^{TQ}(E^N, x_2)$ denote the firm's profit over both periods if the firm does not invest and if does invest, respectively. Furthermore let $E\Delta\Pi^{TQ}(p_2)$ denote the expected increase in profit from investing in period 1.

[13] It is assumed that the firm does not bank any tradable quotas to the second period. Since it has been assumed that the expected present value price of quotas is identical in both periods, the firm does not expect to gain anything from banking tradable quotas to the second period instead of selling them in the first period. This assumption has no impact on the conclusions of the paper but simplifies the presentation.

$$E\Delta\Pi^{TQ}(p_2) = E\left[Max\Pi^{TQ}(E^N, x_2) - Max\Pi^{TQ}(E^0, x_2)\right]$$
$$= \left[p_1 - tE^N\right]\cdot Y_1 + tQ - I^N + E\,max\{Y_2 \cdot \left[p_2 - tE^N\right], 0\} \qquad (8)$$
$$- \left[p_1 - tE^0\right]\cdot Y_1 + tQ + E\,max\{Y_2 \cdot \left[p_2 - tE^0\right], 0\}$$

The firm invests if $E\Delta\Pi^{TQ}(p_2) > 0$

As can be seen from (8), the profit of investment is a function of the expected production decision in period 2, which again is a function of the outcome of the second period price. The outcome of the second-period price determines whether it is profitable for the firm to continue production in the second period or to close down production. It is assumed that the firms expect that the second-period price will fall within the interval $[0, \overline{p}_2]$. There are some critical levels for the outcome of the second-period price that determine whether the firm produces in the second period or not. Let the probability for the three different ranges in outcomes for p_2 be defined by γ_1, γ_3 and γ_2, respectively. Hence,

$$\gamma_1 \equiv Pr(tE^0 < p_2 \leq \overline{p}_2)$$
$$\gamma_2 \equiv Pr(tE^N \leq p_2 \leq tE^0)$$
$$\gamma_3 \equiv Pr(0 \leq p_2 < tE^N) \qquad (9)$$
$$0 \leq \gamma_i \leq 1 \quad i = 1,2,3$$
$$\gamma_1 + \gamma_2 + \gamma_3 = 1$$

Furthermore, let the expected price within each of the three different ranges for outcome of p_2 be denoted $p_2^{\gamma_1}, p_2^{\gamma_2}$ and $p_2^{\gamma_3}$. Hence,

$$p_2^{\gamma_1} \equiv E\left[p_2 \mid tE^0 < p_2 \leq \overline{p}_2\right]$$
$$p_2^{\gamma_2} \equiv E\left[p_2 \mid tE^N \leq p_2 \leq tE^0\right] \qquad (10)$$
$$p_2^{\gamma_3} \equiv E\left[p_2 \mid 0 \leq p_2 < tE^N\right]$$

From the expression for the expected increase in profit from investing given by (8), we can derive the expression for the benefit of investment as a function of the probability distribution for p_2. The expected increase in income from investing is given by

$$E\Delta\Pi^{TQ}(p_2) = \quad t\cdot\left[E^0 - E^N\right]\cdot Y_1 + \gamma_1 \cdot t \cdot \left[E^0 - E^N\right]\cdot Y_2 + \gamma_2 \cdot t \cdot \left[p_2^{\gamma_2} - t\cdot E^N\right]\cdot Y_2 - I^N \qquad (11)$$

The firm implements the investment if the expected increase in profit from investing defined by (11) is larger than zero. From (11) the following proposition is obtained:

> ***Proposition 1:*** *The firm's investment decision is independent of the number of free quotas (Q) under the tradable quota system.*

Furthermore, we see from (4) that the firm produces in period 2 whether it has invested or not if the outcome of p_2 is larger or equal to tE^0. If the outcome of p_2 is less than tE^N, then the firm does not produce whether it has invested or not. If $tE^N \leq p_2 \leq tE^0$, then the firm produces only if it has invested in period 1.

2.2 Non-tradable quotas

Non-tradable quotas imply that the firm cannot sell any surplus of quotas from the first period. A surplus of quotas from the first period has a value for the firm only when the quotas can be used to cover the firm's own requirement for quotas in the second period.

The total short-term income in period 1, denoted $D_{Y_1}^{NT}(Q,E^i)$, is given by

$$\begin{aligned} &i) \quad D_{Y_1}^{NT}(Q,E^i) = Y_1\left[p_1 - tE^i\right] + tQ \quad\quad for\ Q \le E^i \cdot Y_1 \\ &ii) \quad D_{Y_1}^{NT}(Q,E^i) = Y_1\left[p_1\right] \quad\quad\quad\quad for\ E^i \cdot Y < Q \end{aligned} \tag{12}$$

If the firm has not been allotted enough quotas to cover its emissions, (see (12) i)), it must purchase additional quotas on the quota market at a price *t*. If the firm receives more quotas than it needs in period 1, the firm has no emissions costs (see (12) ii)); that is, all its emissions can be covered by the use of the free quotas. Its surplus of quotas ($Q - E^i \cdot Y_1$) can be banked to period 2.

A possible surplus of quotas from period 1 implies that the firm can produce in period 2 without having to purchase quotas as long as it can cover its needs for quotas through the saved quotas from the previous period. When the firm has exhausted its quota reserve, it must purchase quotas on the market in order to continue production. The number of years the firm can produce in the second period without having to buy quotas depends on the initial amount of free quotas, *Q*, and the investment decision in period 1. Let $\bar{y}_2(Q,E^i)$ denote the number of years the firm can produce in the second period without having to buy quotas:

$$\begin{aligned} &i) \quad \bar{y}_2(Q,E^i) = \frac{Q - E^i \cdot Y_1}{E^i} \quad if \quad E^i \cdot Y_1 < Q \\ &ii) \quad \bar{y}_2(Q,E^i) = 0 \quad\quad\quad\quad if \quad Q \le E^i \cdot Y_1 \end{aligned} \tag{13}$$

It is assumed that $\bar{y}_2(Q,E^i) < Y_2$. The implication of this assumption will be discussed in the concluding remarks. Let $\pi_{\bar{y}_2}^{NT}(Q,E^i)$ denote the firm's annual income in period 2 when it meets its need for quotas through banked quotas from the previous period, and let $\pi_{Y_2-\bar{y}_2}^{NT}(E^i)$ denote the firm's annual income in the years after it has exhausted its reserve of banked quotas and must purchase quotas on the market. A profit-maximizing firm produces at least as long as it can meet its needs for quotas through its reserve of banked quotas from the previous period if the following condition is satisfied:

$$\pi_{\bar{y}_2}^{NT}(Q,E^i) = p_2 \quad \ge 0 \tag{14}$$

Since the second period price is assumed to fall within the interval $\left[0,\bar{p}_2\right]$, (14) is always satisfied.

The firm continues production after it has exhausted its reserve banked quotas if the following condition is satisfied:

$$\pi_{Y_2-\bar{y}_2}^{NT}(E^i) = p_2 - tE^i \ge 0 \qquad i = N,O \tag{15}$$

This means that if the outcome of the second-period price is sufficiently high to ensure profitable production even if the firm has to pay for the quotas, the firm produces throughout the entire second period, that is, Y_2-years. Otherwise, the firm produces only as long as it can meet its need for quotas by drawing on the reserve of banked quotas from period 1.

There are hence two possible outcomes for the production in period 2.

$$x_2 \in \{ \bar{y}_2, Y_2 \} \tag{16}$$

where $\bar{y}_2$ is defined by (13). The firm's profit maximizing production in the second period is a function of the outcome of the second period price, hence $x_2(p_2)$.

Let $D^{NT}_{\bar{y}_2}(E^i, Q, p_2)$ denote the income from producing in period 2 until the firm has no quotas left and let $D^{NT}_{Y_2}(E^i, Q, p_2)$ denote the income in period 2 if the firm continues production the entire period.

$$D^{NT}_{\bar{y}_2}(E^i, Q, p_2) = \bar{y}_2(Q, E^i) \cdot [p_2] \qquad i = 0, N \tag{17}$$

$$D^{NT}_{Y_2}(E^i, Q, p_2) = \bar{y}_2(Q, E^i) \cdot [p_2] + (Y_2 - \bar{y}_2(Q, E^i)) \cdot [p_2 - tE^i] \qquad i = 0, N \tag{18}$$

Inserting for $\bar{y}_2$, (defined by (13)), we see that the above income functions can be rewritten as

$$\begin{aligned} &i)\ D^{NT}_{\bar{y}_2}(E^i, Q, p_2) = \frac{p_2}{E^i} \cdot (Q - E^i \cdot Y_1) \quad for\ E^i \cdot Y_1 < Q \\ &ii)\ D^{NT}_{\bar{y}_2}(E^i, Q, p_2) = 0 \qquad for\ Q \le E^i \cdot Y_1 \qquad i = 0, N \end{aligned} \tag{19}$$

$$\begin{aligned} &i)\ D^{NT}_{Y_2}(E^i, Q, p_2) = Y_2 \cdot [p_2 - tE^i] + t(Q - E^i \cdot Y_1) \qquad for\ E^i \cdot Y_1 < Q \\ &ii)\ D^{NT}_{Y_2}(E^i, Q, p_2) = Y_2 \cdot [p_2 - tE^i] \qquad for\ Q \le E^i \cdot Y_1 \qquad i = 0, N \end{aligned} \tag{20}$$

If we compare (19) with (20), we see that as long as $\bar{y}_2(Q, E^i) < Y_2$,

$$\begin{aligned} &D^{NT}_{Y_2}(E^i, Q, p_2) \ge D^{NT}_{\bar{y}_2}(E^i, Q, p_2) \quad for\ p_2 \ge tE^i \\ &D^{NT}_{Y_2}(E^i, Q, p_2) < D^{NT}_{\bar{y}_2}(E^i, Q, p_2) \quad otherwise \end{aligned} \tag{21}$$

Let $\Pi^{NT}(E^0, Q, x_2)$ and $\Pi^{NT}(E^N, Q, x_2)$ denote the firm's maximum profit over both periods if the firm keeps the old technology and if it invests, respectively.

The firm's expected maximum profit over both periods if the firm invests in period 1, denoted $E\Pi^{NT}(E^N, Q, x_2)$ is given by

$$\begin{aligned} E\Pi^{NT}(E^N, Q, x_2) &= E\left[max\{ \Pi^{NT}(E^N, Q, Y_2), \Pi^{NT}(E^N, Q, \bar{y}_2)\right] \\ &= D^{NT}_{Y_1}(E^N, Q) - I^N + E\left[max\{ D^{NT}_{Y_2}(E^N, Q, p_2), D^{NT}_{\bar{y}_2}(E^N, Q, p_2)\}\right] \end{aligned} \tag{22}$$

The firm's expected maximum profit over both periods if the firm produces but does not invest in period 1, denoted $E\Pi^{NT}(E^0, Q, x_2)$, is given by

$$\begin{aligned} E\Pi^{NT}(E^0, Q, x_2) &= E\left[max\{ \Pi^{NT}(E^0, Q, Y_2), \Pi^{NT}(E^0, Q, \bar{y}_2)\}\right] \\ &= D^{NT}_{Y_1}(E^0, Q) + E\left[max\{ D^{NT}_{Y_2}(E^0, Q, p_2), D^{NT}_{\bar{y}_2}(E^0, Q, p_2)\}\right] \end{aligned} \tag{23}$$

The expected increase in profit from investing, denoted $E\Delta\Pi^{NT}(Q, p_2)$, is the difference between the expected profit over both periods if the firm does invest and the expected profit over both periods if the firm does not invest.

$$\mathrm{E}\,\Delta\Pi^{NT}(Q,p_2) = E\Pi^{NT}(E^N,Q,x_2) - E\Pi^{NT}(E^0,Q,x_2) \qquad (24)$$

The firm invests if this expression is positive.

As discussed previously, the firm's production decision in period 2 is dependent on the investment decision made in period 1. In order to discuss the impact on the firm's production decision, we have to consider how the number of free quotas (Q) influences the firm's investment decision. The impact of the number of free quotas on the firm's investment decision is, however, not straight-forward, as it depends on the difference between the number of free quotas and the firm's emissions and potential for emissions reductions. The following section analyzes the impact on investment by considering the three different relevant ranges for the number of free quotas. Section 2.2.1 considers the situation where the number of free quotas is less than the firm's emissions after investing in abatement technology, that is $Q \le E^N \cdot Y_1$. Section 2.2.2 considers the situation where the number of quotas exceeds the emissions *ex ante* of investment, that is $E^0 \cdot Y_1 < Q$. Finally, section 2.2.3 considers the situation where the number of free quotas allotted does not sufficiently meet the need for quotas in period 1 if the firm does not invest in abatement technology, but it exceeds the amount needed if the firm does invest, that is $E^N \cdot Y_1 < Q \le E^0 \cdot Y_1$.

2.2.1 $Q \le E^N \cdot Y_1$

If the amount of quotas received is not sufficient (or is exactly sufficient) to cover the need for quotas even if the firm invests in new abatement technology, the firm has no free non-tradable quotas to bank to the second period. All free quotas are spent during the first period, and the firm must buy additional quotas on the market. The firm's income in the first period is given by (12) i). Since the firm has no banked quotas from the previous period in period 2, we see from (13) that $\bar{y}_2(Q,E^i) = 0$, for both E^N and E^0. Hence, the firm either continues production throughout the entire second period or it closes down production at the end of the first period. The firm produces in the second period if, and only if, $p_2 \ge tE^i$. This implies that the firm's income and production decision in period 2 is dependent on the investment in period 1 but is unaffected by the number of free quotas received in period 1.

The firm's expected increase in income from investing is identical to the expected increase in income from investing under the tradable quota system given by (11). That is,

$$E\Delta\Pi^{NT}(Q,p_2) = \quad t\cdot\left[E^0 - E^N\right]\cdot Y_1 + \gamma_1\cdot t\cdot\left[E^0 - E^N\right]\cdot Y_2 + \gamma_2\cdot t\cdot\left[p_2^{\gamma_2} - t\cdot E^N\right]\cdot Y_2 - I^N \qquad (25)$$

The firm implements the investment if the expected increase in profit from investing is positive.

> ***Proposition 2:*** *The firm's investment decision is independent on the number of free quotas (Q) under the non-tradable quota system if the number of free quotas is less than total emissions after implementing new abatement technology in the first period.*

2.2.2 $E^0 \cdot Y_1 < Q$

One can argue that there is no reason for the government to allocate more quotas to the firm than its initial emissions. However, this situation can occur when a firm is allocated fewer quotas than its historical emissions would indicate but, during the first Kyoto period, it emits far less than it did during the historic year the allocation is based on. The firm may for instance have reduced its production or implemented some technological changes that also have reduced its emissions per unit of output. Furthermore, the firm may have implemented some low-cost abatement option that has resulted in a significant reduction in emissions. The abatement option considered in this paper can thus be perceived as an additional abatement option that can reduce emissions even further.

From the income function given by (19)i) and (20) i) and (21), we find that the maximum income in the second period if the firm has not invested is given by

$$\begin{aligned} & max\{ D^{NT}_{Y_2}(E^0,Q,p_2), D^{NT}_{y_2}(E^0,Q,p_2)\} \\ &= D^{NT}_{Y_2}(E^0,Q,p_2) = Y_2\cdot\left[p_2 - tE^0_2\right] + t\cdot(Q-E^0_1\cdot Y_1) \qquad for \quad tE^0 < p_2 \le \overline{p}_2 \\ &= D^{NT}_{\overline{y}_2}(E^0,Q,p_2) = p_2\cdot\left(\frac{Q-E^0\cdot Y_1}{E^0}\right) \qquad for \quad 0 \le p_2 \le tE^0 \end{aligned} \tag{26}$$

The maximum income in the second period if the firm has invested is given by

$$\begin{aligned} & max\{ D^{NT}_{Y_2}(E^N,Q,p_2), D^{NT}_{y_2}(E^N,Q,p_2)\} \\ &= D^{NT}_{Y_2}(E^N,Q,p_2) = Y_2\cdot\left[p_2 - tE^N_2\right] + t\cdot(Q-E^N_1\cdot Y_1) \qquad for \quad tE^N < p_2 \le \overline{p}_2 \\ &= D^{NT}_{\overline{y}_2}(E^N,Q,p_2) = p_2\cdot\left(\frac{Q-E^N\cdot Y_1}{E^N}\right) \qquad for \quad 0 \le p_2 \le tE^N \end{aligned} \tag{27}$$

It follows from (9)-(10), (12) ii), (22) - (24), (26) and (27) that the expected increase in profit from investing, $E\Delta\Pi^{NT}(Q,p_2)$ is given by

$$\begin{aligned} & E\Delta\Pi^{NT}(Q,p_2) = \gamma_1\left[t\cdot(E^0-E^N)\cdot Y_1 + t\cdot(E^0-E^N)\cdot Y_2\right] \\ & +\gamma_2\left[(p_2^{\gamma_2} - t\cdot E^N)\cdot Y_2 + t(Q-E^N\cdot Y_1) - p_2^{\gamma_2}\cdot(\frac{Q-E^0\cdot Y_1}{E^0})\right] \\ & +\gamma_3\cdot\left[p_2^{\gamma_3}\cdot Q\cdot(\frac{1}{E^N}-\frac{1}{E^0})\right] \quad - I^N \end{aligned} \tag{28}$$

The firm implements the investment if the expected income from investing defined by (28) is larger than zero.

From (28) the following propositions are obtained:

> ***Proposition 3:*** *The firm's expected increase in income from investing in abatement technology is a function of the number of free quotas received in period 1 (for $E^0\cdot Y_1 < Q$). The larger the amount of quotas, the larger the expected benefit of investment in period 1.*

Proof: The derivative of the expected benefit of investment with respect to Q is given by

$$\frac{\delta(E\Delta\Pi^{NT}(Q,p_2))}{\delta Q} = \gamma_2\left[t-\frac{p_2^{\gamma_2}}{E^0}\right] + \gamma_3\cdot\left[p_2^{\gamma_3}\cdot(\frac{1}{E^N}-\frac{1}{E^0})\right] \tag{29}$$

It follows from the definition of $p_2^{\gamma_2}$ given by (10) and the fact that $E^0 > E^N$ that the equation above is positive.

The explanation for proposition 3 is that when the firm receives more quotas than it needs in period 1, any additional quotas received in period 1 only have value for the firm if it produces in the second period. The expected increase in income in the second period following from an increase in Q is higher when the firm has invested than if it has not. The reason for this is two-fold. First, an investment in the first period increases the probability that it will be profitable for the firm to produce throughout the entire second period. That increases the value of an additional banked quota compared to a situation where the firm only produces until the reserve of banked quotas is exhausted. Second, even if the outcome of the second period price is so low that the firm only finds it profitable to produce until the reserve of banked quotas is exhausted, the investment increases the income in period 2. Since the emission per unit production is less when the firm has invested, an increase in the banked quotas leads to a higher increase in production and hence income in period 2 when the firm has invested.

2.2.3 $E^N \cdot Y_1 < Q \le E^0 \cdot Y_1$

In this case, the firm has no quotas to transfer to the second period unless it implements the investment in new, less emissions-intensive technology. Hence, the firm will not find it profitable to produce at all in the second period if it has not invested, and the outcome of p_2 is less than $t \cdot E^0$. The maximum income in the second period if the firm has not invested is independent of Q when all quotas are used in the first period, that is, $Q \le E^0 \cdot Y_1$, and is given by

$$\begin{aligned} &max\{ D^{NT}_{Y_2}(E^0 ,Q, p_2), D^{NT}_{\bar{y}_2}(E^0 ,Q, p_2)\} \\ &= D^{NT}_{Y_2}(E^0 ,Q, p_2) = Y_2 \cdot \left[p_2 - tE^0 \right] \qquad for \quad tE^0 < p_2 \le \bar{p}_2 \\ &= D^{NTQ}_{\bar{y}_2}(E^0 ,Q, p_2) = \quad 0 \qquad\qquad for \quad 0 \le p_2 \le tE^0 \end{aligned} \tag{30}$$

The maximum income in the second period if the firm has invested is a function of Q, since some of the quotas received in period 1 are banked to period 2, that is, $E^N \cdot Y_1 < Q$, and is given by (27).

It follows from (9)-(10), (12) i) and ii), (22) - (24), (30) and (27) that the increase in expected profit from investing is given by

$$\begin{aligned} &E\Delta\Pi^{NT}(Q, p_2) = t \cdot (E^0 \cdot Y_1 - Q) + \gamma_1 \left[t \cdot (Q - E^N \cdot Y_1) + t \cdot (E^0 - E^N) \cdot Y_2 \right] \\ &+ \gamma_2 \left[(p_2^{\gamma_2} - t \cdot E^N) \cdot Y_2 + t(Q - E^N \cdot Y_1) \right] \\ &+ \gamma_3 \cdot \left[p_2^{\gamma_3} \cdot (\frac{Q - E^N \cdot Y}{E^N}) \right] \quad - I^N \end{aligned} \tag{31}$$

The firm implements the investment if the expected income from investing is larger than zero.

> ***Proposition 4****: The larger the amount of quotas allocated, the lower the expected benefit of investment in period when* $E^N \cdot Y_1 < Q \le E^0 \cdot Y_1$.

Proof: We see from (31) that the firm's investment decision is dependent on the amount of quotas (Q) it receives. The derivative of the expected benefit of investment with respect to Q is given by

$$\frac{\delta(E\Delta\Pi^{NT}(Q,p_2))}{\delta Q} = \gamma_3 \cdot (\frac{p_2^{\gamma_3}}{E^N} - t) \qquad (32)$$

It follows from the definition of $p_2^{\gamma_3}$ given by (10) that the equation above is negative for $\gamma_3 > 0$.

The explanation for proposition 4 is that if the firm does not invest, then an increase in the number of free quotas is put towards meeting the need for quotas in the first period, since the number of free quotas is less or equal to emissions ($Q \leq E^0 \cdot Y_1$). The value of an additional quota is then equal to the quota price *t*. However, if the firm invests, some of the free quotas from period 1 are banked to the second period since the number of free quotas exceeds the emissions when the firm has invested ($E^N \cdot Y_1 < Q$). The value of an additional quota will in that case be less than *t* if the outcome of the second-period price is so low that the firm produces only as long as it can meet its need for quotas by drawing on the reserve of banked quotas from period 1.

3 Comparison of tradable and non-tradable free quotas

This section compares the two different quota systems with respect to their ability to prevent the firm from closing down production in the second period. As shown in the previous section, investment in new abatement technology increases the firm's profit from producing in the second period because emissions, and hence emissions costs, decrease when the firm has invested (see (4) and (13)-(15)). Hence, the differences in the firm's investment decisions following from the two different quota systems are important for the evaluation of the quota system's ability to prevent firms from closing down production. The investment conditions for the two different quota systems were derived in the previous section. The firm invests if the expected increase in income from investing is positive. The quota system that leads to the highest expected increase in income from investing is the one that most increases the likelihood that the firm will invest. Hence, the difference between the expected increase in income from investing between the two quota systems determines which of the two quota systems provides the greatest incentive to invest.

As seen from the previous section, the firm's investment decision is dependent on the number of free quotas received under the non-tradable quota system. This section compares the system of free tradable quotas with the system of free non-tradable quotas for the same three different ranges of amounts of free quotas distributed to the firm, as considered in sections 2.2.1-2.2.3.

3.1 $Q \leq E^N \cdot Y_1$

Proposition 5: *If the amount of quotas received does not exceed the need for quotas even if the firm invests in new abatement technology, the firm's investment and production decisions are identical and independent of Q under both quota systems.*

Proof: We see from (7), and (19)ii), (20) ii) and (21), that the short-term income function is identical under the tradable and non-tradable quota systems when $Q \leq E^N \cdot Y_1$. Furthermore, as stated in section 2.2.1, the expression for the firm's expected benefit of investment under the non-tradable quota system given by (25) is identical to the expressions for the firm's expected benefit of investment, given by (11), under the tradable quota system. (See also propositions 1 and 2).

If the amount of quotas received is not sufficient to cover the need for quotas even if the firm invests in new abatement technology, the firm has no free non-tradable quotas to bank to the second period. In that case, the firm's income in period 2 is independent of the amount of free quotas received in period 1. Whether the free quotas can be sold or not is irrelevant for the firm as long as at the firm is a net buyer of quotas.

3.2 $E^0 \cdot Y_1 < Q$

To highlight the difference between the two quota systems, it is useful to divide the number of quotas that exceeds the emissions in period 1 into two parts. The expression $(Q - E^0 \cdot Y_1)$ represents the surplus of quotas in period 1 prior to investment in abatement technology, whereas $(E^0 - E^N) \cdot Y_1$ represents the additional surplus if investment is implemented.

When the number of free quotas exceeds the firm's emission prior to investment, it follows from (11) and (28) that the difference between the expected benefit of investment under the tradable quota system and the expected benefit of investment under the non-tradable quota system, that is $E\Delta\Pi^{TQ}(Q, p_2) - E\Delta\Pi^{NT}(Q, p_2)$, is given by

$$\gamma_2 \cdot \left[(p_2^{\gamma_2} - t \cdot E^0) \cdot (Q - E^0 \cdot Y_1) \right] + \gamma_3 \cdot \left[(t - \frac{P_2^{\gamma_3}}{E^N}) \cdot (E^0 - E^N) \cdot Y_1 - p_2^{\gamma_3} \cdot (Q - E^0) \cdot (\frac{1}{E^N} - \frac{1}{E^0}) \right] \quad (33)$$

From (33), and the model section, we obtain propositions 6 through 10:

> ***Proposition 6****: One cannot in general say whether the tradable quota system or the non-tradable quota system makes it more likely that the firm invests when $E^0 \cdot Y_1 < Q$. This depends on the probability distribution of the second period price, the number of quotas distributed free of charge and the emission reduction following from the investment.*

Proof: Let the term within the square brackets that is multiplied by γ_2 be denoted the first term of (33), and let the term within the square brackets that is multiplied by γ_3 be denoted the second term. The first term of (33) cannot be negative since $p_2^{\gamma_2} \leq t \cdot E^0$. The second term of (33) can be positive or negative depending on whether the absolute value of $(t - \frac{P_2^{\gamma_3}}{E^N}) \cdot (E^0 - E^N) \cdot Y_1$ exceeds $p_2^{\gamma_3} \cdot (Q - E^0) \cdot (\frac{1}{E^N} - \frac{1}{E^0})$.

To interpret proposition 6, the two terms of (33) are discussed separately. The first term of (33) is the difference in income from investing if the outcome of the second period price is characterized by $t \cdot E^N \leq p_2 \leq t \cdot E^0$. Hence, the firm produces throughout the entire period if it has invested. The difference between the two systems follows from how investment within the non-tradable quota system can increase the firm's value of the surplus of quotas prior to investment, that is $(Q - E^0 \cdot Y_1)$. When the quotas are tradable, the firm's benefit from receiving a surplus of quotas prior to investment equals $t \cdot (Q - E^0 \cdot Y_1)$, whether the firm produces in the second period or not. (The surplus of quotas can be sold in period 1.) However, when the quotas are non-tradable, the firm can only benefit from the surplus of quotas received in period 1if it produces in period 2. If the firm invests, the value of these quotas equals $t \cdot (Q - E^0 \cdot Y_1)$ in period 2. If the firm does not invest, the value of these quotas equals the profit achieved in the second period by producing until the reserve of banked quotas is exhausted ($\bar{y}_2(Q,E^0)$ years). When $p_2 < t \cdot E^0$, the second period value of the surplus of free quotas in the first period, prior to investment, is higher when the firm has invested than when it has not. Note that the impact of investment on the *increase* in banked quotas under the non-tradable quota system, that is $(E^0 - E^N) \cdot Y_1$, does not lead to any differences between the two systems for $t \cdot E^N \leq p_2 \leq t \cdot E^0$.

The second term of (33) expresses the difference in increased income from investing between the two systems when $p_2 < t \cdot E^N$. Hence, the profit of producing in the second period if the firm has to pay for the quotas is negative. In that case, the difference in increased income from investing between the two systems consists of two effects with an opposite sign. One of the effects relates to the increase in banked quotas resulting from investing $(E^0 - E^N) \cdot Y_1$, and the other relates to the value of the initial surplus of quotas before investment takes place $(Q - E^0 \cdot Y_1)$.

A firm that receives tradable quotas will close down production in the second period when $p_2 < t \cdot E^N$. The total benefit from investing would in that case be $t \cdot (E^0 - E^N) \cdot Y_1$. When the quotas are non-tradable, the firm must produce in the second period to receive any profit from the surplus of quotas in the first period. The value of the increase in banked quotas resulting from investing equals $\frac{p_2^{\gamma_3}}{E^N} \cdot (E^0 - E^N) \cdot Y_1$ under a non-tradable quota system and is hence less than under the tradable quota regime for $p_2 < t \cdot E^N$. This effect makes it *cet. par.* less profitable to invest under the non-tradable quota regime than under the tradable quota regime. The smaller p_2, the smaller is this part of the benefit of investment under the non-tradable quota system.

However, if the firm has invested, the profit from spending the first-period surplus of quotas (prior to investment) $(Q - E^0 \cdot Y_1)$ in the second period is larger than when no investment is made. Since the firm emits less when it has invested, the banked surplus of quotas prior to investment from period 1 implies that it can produce for more years in the second period without having to buy quotas. This part of the benefit from investing is hence given by $p_2^{\gamma_3} \cdot (Q - E^0) \cdot \left[\frac{1}{E^N} - \frac{1}{E^0} \right]$. This effect will *cet. par.* make it more profitable to invest under a non-tradable quota regime than under a tradable quota regime.

> ***Proposition 7:*** *There is no difference regarding a firm's investment and production decision under tradable or non-tradable quota systems when the firm is certain that the second period price is sufficiently high to ensure that it is profitable to continue production throughout the entire second period irrespective of any investment in the first period. The firm invests and produces the whole second period under both systems.*

Proof: If the firm is certain that it is profitable to produce the entire second period whether or not it has invested in the first period, then $\gamma_1 = 1$. If $\gamma_1 = 1$, then $\gamma_2 = \gamma_3 = 0$ because $\gamma_1 + \gamma_2 + \gamma_3 = 1$. The difference between the expected benefit of investment under the tradable quota system and the expected benefit of investment under the non-tradable quota system expressed by (33) hence equals zero when $\gamma_1 = 1$. Equations (2), (11) and (28) ensure that the firm invests under both systems, and it follows from the (4) and (15) that the firm produces the entire second period when $t \cdot E^0 < p_2$.

The explanation for proposition 7 is that the difference between the tradable and the non-tradable quota systems is that the firm does not accrue the benefit from the surplus of quotas from period 1 before the second period, in terms of banked quotas under the latter system. When it is profitable for the firm to produce in the second period, whether or not it has invested, the value of the banked quotas equals the number of banked quotas multiplied by the quota price. Under the tradable quota system, if the firm invests in abatement technology, it receives the income from reduced emissions in the first period in the same period. The income is received in terms of tradable quotas. The total increased short-term profit over both periods is equal between the two different quota systems, but distributed differently over periods.

Proposition 8: *The larger the initial amount of allocated quotas, the more likely that the non-tradable quota system to a larger extent than the tradable quota system will induce the firm to invest when* $E^0 \cdot Y_1 < Q$.

Proof: We see from (33) that the difference in benefit from investing between the two different quota systems decreases in Q. See also propositions 1 and 3.

Proposition 9: *The larger the initial allocation of free quotas, the greater the likelihood that during the second period the firm will remain competitive under the non-tradable quota system than under the tradable quota system (for* $E^0 \cdot Y_1 < Q$ *).*

Proof: See proposition 8. And as demonstrated in the model section ((4) and (14)-(15)), investment in period 1increases the profit of producing during the second period under both systems and hence make it more likely that it is profitable to produce throughout the entire second period if the firm has invested.

Proposition 10: *Even if it is not profitable for a firm to produce throughout the entire second period, a larger initial allocation of free non-tradable quotas implies that the firm will continue production for more years in the second period than it would if the quotas were tradable (for* $E^0 \cdot Y_1 < Q$ *).*

Proof: We see from (13) that $\bar{y}_2(Q, E^0)$ is increasing in Q for $E^0 \cdot Y_1 < Q$. The production condition under the tradable quota system, given by (4), states that the firm will close down production in period 2 if it is not profitable to produce throughout the entire period.

3.3 $E^N \cdot Y_1 < Q \leq E^0 \cdot Y_1$

When the number of free quotas allocated is less than the initial emissions prior to investment, but larger than emissions after the investment has been implemented, the difference between the expected benefit of investment under the tradable quota system and the expected benefit of investment under the non-tradable quota system, that is $E\Delta\Pi^{TQ}(Q, p_2) - E\Delta\Pi^{NT}(Q, p_2)$, is given by

$$\gamma_3 \cdot \left[t \cdot \left[Q - E^N \cdot Y_1 \right] - p_2^{\gamma_3} \cdot \left(\frac{Q - E^N \cdot Y}{E^N} \right) \right] \quad (34)$$

From (34) the following propositions are obtained:

***Proposition 11**: It is less likely that the firm will invest under the non-tradable quota system than under the tradable quota system when $E^N \cdot Y_1 < Q \leq E^0 \cdot Y_1$. It is therefore also less likely that it will be profitable for the firm to continue production throughout the entire second period under the non-tradable quota system than under the tradable quota system.*

Proof: The expression given by (34) is negative since $p_2^{\gamma_3} < t \cdot E^N$. As demonstrated in the model section ((4) and (14)-(15)), investment in period 1increases the profit of producing in the second period under both systems, and hence make it more likely that it is profitable to produce the whole second period.

As argued in the previous section it is the increased benefit of the surplus of quotas prior to investment from the first period, $(Q - E^0 \cdot Y_1)$, that can make the investment more profitable under the non-tradable quota system than under the tradable quota system. If $E^N \cdot Y_1 < Q \leq E^0 \cdot Y_1$, then a firm that has not implemented the investment in period 1 has no surplus of quotas to bank to period 2. Hence the investment in period 1 will not increase the second period profit of the banked surplus of quotas prior to investment from period 1.

***Proposition 12**: As long as $E^N \cdot Y_1 < Q \leq E^0 \cdot Y_1$, an increase in Q increases the difference between the benefit of investment under the two different quota systems.*

Proof: The expression given by (34) is decreasing in Q since $p_2^{\gamma_3} < t \cdot E^N$. See also propositions 1 and 4.

4 Concluding remarks

The purpose of this paper has been to compare a tradable quota system with a non-tradable quota system when it comes to their impact on firms' investment and production decisions. The main conclusion that can be drawn here is that, when banking is permitted, it remains unclear whether or not a non-tradable quota system provides less incentive to invest in abatement technology than does a tradable quota system. Whether the tradable quota system or the non-tradable quota system makes it more likely that the firm invests in abatement technology and continues production depends on the probability distribution of the second period price and the number of quotas distributed free of charge.

This paper has shown that the two systems provide equal incentives to invest in abatement technology and produce during the second period if the amount of free quotas is small – that is, less than the level of emissions if the abatement option is implemented – or if the firm knows that will be profitable to produce in the second period regardless of whether or not it has invested in abatement technology.

The firm will be more likely to invest in new abatement technology under the tradable quota system than under the non-tradable quota system if the amount of free quotas exceeds the level of emissions that will occur if the abatement option is implemented but is less than the initial amount of emissions prior to investment. However, if the amount of free quotas is larger than the firm's emission before the abatement option is implemented, the firm's expected profit of investment may be larger under the non-tradable quota system than under the tradable quota system. The larger the amount of free quotas allocated in the first period, the more likely is it that the firm implements investment in abatement technology under the non-tradable quota system. And the more likely is it that the firm is competitive also in subsequent periods.

This paper has demonstrated that it is the fact that investment in abatement technology in the first period increases the value of the surplus of quotas from period 1 that can make it more likely for a firm to invest under a non-tradable quota system than a tradable quota system. The investment decision in the first period is an irreversible decision that influences the emissions cost over both periods. If the firm's abatement option in the first period did not affect the second period emissions, the expected increase in profit from abatement in the first period would always be higher under the tradable quota system than under the non-tradable quota system. Hence, if the firm's abatement option is to reduce emissions through, for instance, a fuel switch that only increases annual production costs as long as the abatement option is sustained, the firm's incentive to implement the abatement option is less under a non-tradable quota system than under tradable quota system. However, even though it is less likely that the firm in that case will abate under the non-tradable quota system, it is more likely that the firm will continue production for a longer period. Although the second period price does not cover the production cost if the firm has to pay for the quotas, the firm will also produce for some part of the second period until it has exhausted its reserve of banked quotas from the first period.

Some of the assumptions we have made in this paper can only be justified if the lengths of the two periods considered (Y_1 and Y_2) do not differ considerably. If the number of years in Y_2 is sufficiently larger than the number of years in period 1, it is less likely to be unprofitable to invest in the second period (as assumed in (2) i)) if the investment is profitable if the firm produces in both periods (as assumed in (2) ii). If it is profitable to invest in period 2, it is more likely that the firm will postpone the investment to the second period if the free quotas are non-tradable than if they were tradable. If the investment option is profitable in the second period, the investment in the first period has no effect on the short-run profit in the second period, because the investment will be implemented if the firm produces. The decision to "not invest" in the first period is in that case not irreversible. Since it was the irreversibility of the investment decision in period 1 that could lead to higher probability for investment when the free quotas were non-tradable, it will always be more likely that the firm will invest under the tradable quota regime when it is profitable to invest in the second period if the firm continues production in that period.

It has also been assumed here that the number of years in which the firm can meet its need for quotas in period 2 by drawing on banked quotas from the previous period is less than then number of years in period 2. That is, $\bar{y}_2(Q,E^N) < Y_2$. If Y_2 is very small compared to Y_1, it is less likely that this assumption is satisfied. If the assumption is not satisfied, the incentives for investment under the non-tradable quota system would be reduced because the firm would not able to utilize all the banked quotas from period 1 even if it produces throughout the entire second period.

This paper has compared a system where the quotas given free of charge are non-tradable with a system where the free the quotas are tradable. Both systems imply that the domestic fulfillment of a climate agreement is not cost effective. Firms that no longer produce with a positive profit continue production because of the free quotas, which is indeed the purpose of the free quotas. Within the model used in this paper, the number of free quotas allocated is identical under both systems. As shown in the paper, the two different systems may lead to some differences regarding the firm's investment in abatement technology in the period they receive free quotas and production decision in the years thereafter. In the choice of free-quota system, the regulator would probably also put weight on the differences in transaction costs. An advantage of the non-tradable quota system is that the transaction costs and possible inefficiencies resulting from the problems with conditional allocation of tradable quotas, as discussed in the introduction, can be significantly reduced.

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