CICERO

Center for
International Climate
and Environmental
Research - Oslo

Working Paper 1996:02

The Design of a Tradeable CO_2-quota System under Market Imperfections

Cathrine Hagem and Hege Westskog

University of Oslo

ISSN: 0804-452X

Working Paper 1996:2

The Design of a Tradeable CO_2-quota System under Market Imperfections

by

Cathrine Hagem and Hege Westskog*

August 1996

* SUM, P.O. Box 1116 Blindern, N-0317 Oslo, Norway

ISSN: 0804-452X

The Design of a Tradeable CO_2-quota System under Market Imperfections[*]

by

Cathrine Hagem[**] **and** **Hege Westskog**[***]

Abstract

Market power within a system of tradeable CO_2-quotas leads to a non-optimal distribution of abatement across countries. In this paper we introduce a quota system that may reduce the adverse effects of market power, and thereby result in a distribution of abatement *across countries* that is closer to a cost-effective outcome. However, this system leads to a non-optimal distribution of abatement *across periods*. Hence, we face a trade-off between a cost-effective distribution of abatement across periods and reduced adverse effects of market power.

Key words: CO_2-quotas, climate policy, market power, durable goods

[*] Comments from Rolf Golombek, Michael Hoel, Snorre Kverndokk and Asbjørn Torvanger are highly appreciated.

[**] CICERO, P.b.1129, Blindern, 0317 Oslo, Norway, e-mail: cathrine.hagem@cicero.uio.no

[***] SUM, P.b.1116, Blindern, 0317 Oslo, Norway, e-mail: hege.westskog@sum.uio.no

1. Introduction

Tradeable quotas are often proposed as a policy instrument in an international agreement to reduce emissions of CO_2. Tradeable quotas will ensure a cost-effective distribution of abatement if the market for quotas is competitive, which implies that only price-taking countries operate in the market for quotas. In a tradeable quota system, each country receives an initial amount of CO_2-quotas, which can be traded. In a competitive market for quotas it is optimal for all countries to sell (buy) quotas as long as the market price of quotas is higher (smaller) than their own marginal abatement cost since their emissions cannot exceed the total amount of quotas held by the country. Furthermore, if each country could allocate the use of quotas freely across periods, it is optimal for them to distribute abatement across periods such that their present value of marginal abatement costs across periods are equalized. In equilibrium, marginal abatement costs are equalized across all countries and across all periods, which is a cost-effective distribution of abatement.

The distribution of the economic burden of the climate agreement will be determined by the initial allocation of quotas. As proven by Montgomery (1972), the cost-effective distribution of abatement will be obtained regardless of the initial allocation of quotas as long as the quota market is competitive. Hence, there is separability between considerations of effectiveness and considerations of equity - any distribution of CO_2-quotas between countries could be achieved cost-effectively.

When we consider the share of the world's CO_2-emissions of different countries, it is obvious that all countries cannot be considered as price-takers. The United States, China and Russia had a share of the world's CO_2 emissions from industrial processes in 1992 of 22%, 12% and 9% respectively (World Resources Institute, 1996 (1992 figures). Those countries would probably trade a larger share of the total amount of quotas than countries with lower share of world emissions, and could possibly exercise market power in the market of tradeable quotas.

It has long been established that market power within a static system of tradeable quotas could result in inefficiencies. Hahn (1984) looks at a situation where there is one agent with market power, while the rest of the traders are price-takers. He showed that the efficiency loss from market power in such a market depends on the initial allocation of quotas. Hence, there is no longer separability between considerations of effectiveness and considerations of equity in the quota system. Westskog (1996) estimates the efficiency loss from market power in a market for CO_2-quotas for different allocation rules. She shows that equity considerations or compensating countries for joining an agreement of reducing CO_2-emissions through quota allocation, can result in significant efficiency losses in the market for quotas if some of the participants exercise market power.

When countries exercise market power, a cost-effective solution could be achieved by allocating quotas such that the initial allocation of quotas given to a country with market power equals the number of quotas the country wants to have after quota trading has taken place. However, burden sharing issues may set restrictions on how quotas are allocated, and without separability between considerations of equity and effectiveness, efficiency losses due to market power would arise. In this paper we discuss how the design of the quota system can influence the efficiency loss from market power when the distribution of quotas is restricted by equity considerations.[1]

We assume that some (or all) countries participate in a climate agreement where they have agreed on a certain emission target that should be achieved during a period of time. The period length is divided into sub-periods of equal length. The participating countries have agreed on the initial distribution of quotas. We compare two different systems for tradeable quotas in this paper:

1. A system where the quotas entitle the holder to emit a certain amount of CO_2

[1] Equity considerations could also be taken care of by the use of side-payments. If equity considerations are fully taken care of by the use of this kind of lump-sum transfers it possible to obtain a cost-effective solution by allocating quotas such that no country exercises market power. In this paper we consider a climate treaty where side-payments are not accepted as an instrument for burden-sharing.

over the whole length of the period with no restrictions on the allocation of emissions between the different sub-periods. Trade is arranged at the beginning of the period. This system is referred to as *a flexible quota system*.

2. A system where there are restrictions on emissions in each sub-period. The quotas entitle the holder to emit a certain amount of CO_2 in each sub-period, and trade is arranged at the beginning of each sub-period. A quota bought in the first period has a value for the holder in each of the following sub-periods. This is referred to as *a durable quota system*.

A durable quota is comparable to a durable good. It is shown in the literature that when a good is durable and sold by a monopolist in different periods, it is profitable for the monopolist to lower the price in subsequent periods in order to sell additional quotas (see for instance Tirole (1988) for a simple analysis of a durable good monopoly). The buyers will expect that the monopolist will lower the price in future periods in order to sell more quotas. These rational expectations hurt the monopolist because the buyers are willing to pay less for quotas today, when they anticipate a fall in the prices in the future. The monopolist's incentive to sell additional units in each sub-period in the durable quota system can reduce some of the efficiency loss from market power compared to a flexible quota system. However, we will show that the durable quota system could give rise to efficiency losses across periods due to a non-optimal distribution of abatement across periods.

We will show that in a flexible quota system each country will distribute abatement cost-effectively across periods. However, the difference in marginal abatement costs across countries could be higher compared to a durable quota system. Hence, we face a trade-off between a cost-effective distribution of abatement across periods and reduced adverse effects of market power. The trade-off between these two effects is the main topic of this paper.

In the next section we present a model for a durable quota system and a flexible quota system. A comparison of the two quota systems is given in section 3. In section 4 we carry out some numerical illustrations of the cost differences between the two systems by the use of the CO_2-abatement cost functions taken from Bohm and Larsen (1994). Concluding remarks are given in section 5.

2.The model

We consider a situation where some countries (or all countries) participate in a climate treaty where they have agreed on a target level for their total emissions of CO_2 during a certain time period of T years. The emission target is denoted Q^0. They have also agreed on the initial distribution of quotas among the participating countries. One of the countries exercises market power in the tradeable CO_2 quota market. We will in the following assume that this country is a large seller of quotas and is hereafter referred to as the monopolist.[2] All other countries are so small net buyers or sellers of quotas that they can be considered as price-takers. These countries are referred to as the fringe. In total, the fringe is a net buyer of quotas. Furthermore, we assume that none of the countries act strategically in order to influence the outcome of a possible renegotiation of the agreement after time T.

The time period of T years is divided in two equally long sub-periods, period 1 and period 2. Let t_1 and t_2 symbolize the beginning of period 1 and period 2, respectively.

The durable quota system has the following design:

The participants receive quotas at the beginning of period 1 and each quota specifies an emission allowance in period 1 and in period 2. The quota can be characterized as a durable quota - it lasts both periods. Trade is arranged at the beginning of each sub-period. At time t_1 the countries trade quotas that last for two periods. At time t_2 the countries trade quotas that only have a value for the holder for the remaining period (period 2). The durable quota system might be designed such that the quotas give the holder the right to emit different amounts of CO_2 in the two periods. This implies that a quota that specifies an amount of emissions equal to $\bar{q}$ tons entitles the holder of the quota to emit $(1+\sigma)\bar{q}$ tons in period 1 and $(1-\sigma)\cdot\bar{q}$ tons in period 2, where $-1 \leq \sigma \leq 1$.

The initial amount of quotas given to participant *j* in a durable quota system is denoted q_j^0, *j* = M, F, where *M* is the monopolist and *F* is the fringe. The amount of emission allowances in period 1 (Q_1^0), in period 2 (Q_2^0) and the total emission allowances over both periods (Q^0) are thereby:

$$Q_1^0 = (1+\sigma)q_M^0 + (1+\sigma)q_F^0$$

$$Q_2^0 = (1-\sigma)q_M^0 + (1-\sigma)q_F^0 \qquad (1)$$

$$Q^0 = Q_1^0 + Q_2^0 = 2\cdot q_M^0 + 2\cdot q_F^0$$

Note that since there is a target for total emissions it is not possible to let σ differ between countries. If σ was country specific, total emissions achieved after trade in quotas had taken place would depend on the outcome of the trade. We assume in section 2.1 and 2.2 that σ is set to 0 which implies that the quotas give the holder the right to emit the same quantity of CO_2 in each sub-period. The impact of this assumption will be discussed in section 3.

The flexible quota system has the following design:

In a flexible quota system the participant *j* receives quotas that specify the total amount of emission allowances during both periods, which is denoted Q_j^0. The quotas are traded once, at time t_1. Each participant is free to decide the allocation of emissions across periods as long as the total amount of emissions over both periods does not exceed the total amount of quotas held by the participant. The total amount of quotas allocated under this system, is:

---

[2] The general conclusions of this paper is, however, not affected whether we have a monopolist or a monopsonist. This will be discussed in section 3 and 4. The impact of more than one large seller of quotas will be discussed in the last section.

$$Q^0 = Q_M^0 + Q_F^0. \qquad (2)$$

In both a flexible quota system and a durable quota system the total amount of quotas allocated to the participants during the time period *T* is Q^0. To make comparisons possible it is throughout the paper assumed that the initial distribution of the total amount of emission allowances between the fringe and the monopolist during the two periods, is identical in both systems:

$$Q_M^0 = 2 \cdot q_M^0 \text{ and } Q_F^0 = 2 \cdot q_F^0 \qquad (3)$$

Let $C_{ji} = C_{ji}(a)$ define the abatement cost function, where *a* is abatement, *i* denotes the different sub-periods (*i* = 1,2) and *j* = M,F. The abatement cost functions are increasing in the amount of emissions abated and convex ($C'_{ji} > 0, C''_{ji} > 0$). Abatement in country *j* in period *i* (a_{ji}) is the difference between business as usual emissions (Z_{ji}) and the amount the country emits in that period (u_{ji}):

$$a_{ji} = Z_{ji} - u_{ji} \qquad (4)$$

In this paper we compare the durable and the flexible quota system when it comes to the total costs of the two systems. The total cost of a tradeable CO_2-quota system is minimized (the system is cost-effective) when the present value of marginal abatement costs for each period are equalized across countries and across periods. This implies that:

$$\frac{\partial C_{Fi}}{\partial a_{Fi}} = \frac{\partial C_{Mi}}{\partial a_{Mi}} \quad i = 1,2 \qquad (5)$$

and

$$\frac{\partial C_{j1}}{\partial a_{j1}} = \delta \frac{\partial C_{j2}}{\partial a_{j2}} \quad j = F, M \qquad (6)$$

where δ is the discount factor for period 2.

2.1 The durable quota system

The emissions in period 1 equal the initial amount of quotas a country holds for that period, plus (minus) the amount of quotas bought (sold) in period 1. The abatement in period 1 is therefore given by:

$$a_{F1} = Z_{F1} - (q_F^0 + q_1) \quad (7)$$

$$a_{M1} = Z_{M1} - (q_M^0 - q_1) \quad (8)$$

where q_1 is the amount of quotas bought in period 1 by the fringe.

In period 2 a country's emissions equal the initial amount of quotas a country holds for that period plus (minus) the quotas the country bought (sold) in period 1, plus (minus) the extra amount of quotas a country buys (sells) in period 2. The abatement in period 2 is given by:

$$a_{F2} = Z_{F2} - (q_F^0 + q_1 + q_2) \quad (9)$$

$$a_{M2} = Z_{M2} - (q_M^0 - q_1 - q_2) \quad (10)$$

where q_2 is the amount of quotas bought in period 2 by the fringe.

We see from (7)- (10) that:

$$\frac{\partial C_{Fi}}{\partial a_{Fi}} = -\frac{\partial C_{Fi}}{\partial q_i} \text{ and } \frac{\partial C_{Mi}}{\partial a_{Mi}} = \frac{\partial C_{Mi}}{\partial q_i} \quad (11)$$

It follows from (7)-(10) that abatement in period 1 is a function of the business as usual emission (Z) and the quotas bought/sold in period 1, while the abatement in period 2 is a function of the business as usual emission (Z) in that period and the amount of quotas bought/sold in both periods.

The fringe's marginal benefit of buying a quota in period 1 equals the present value of the cost savings from not abating that amount of emissions in period 1 and in period 2. The fringe's demand for quotas in period 1 is affected by the possibility of buying quotas in period 2 at a lower price. We assume that the fringe has perfect foresight about the quota price in period 2. The price the fringe is willing to pay for one quota in period 1 is equal to the marginal benefit of that quota in period 1 plus the present value of the price of a quota in period 2. Therefore we have:

$$p_1 = \frac{\partial C_{F1}}{\partial a_{F1}} + \delta p_2 \tag{12}$$

where p_1 is the price of a quota in period 1 and p_2 is the price of a quota in period 2.

This gives the following demand function for quotas in period 1: $p_1 = p_1(q_1, p_2)$

The fringe's demand for quotas in period 2 depends on the marginal benefit the fringe obtains from buying a quota in that period:

$$p_2 = \frac{\partial C_{F2}}{\partial a_{F2}} \tag{13}$$

This gives the following demand function for quotas in period 2: $p_2 = p_2(q_1 + q_2)$

In period 2 the monopolist minimizes the costs of abatement in period 2 minus the income from selling quotas, given the fringe's demand function for quotas in this period:

$$\underset{q_2}{\text{Min}} \left\{ C_{M2}(a_{M2}) - p_2(q_1 + q_2) \cdot q_2 \right\} \tag{14}$$

Solving (14) and inserting from (11) gives the following first order condition for the monopolist's cost minimization problem in period 2:

$$\frac{\partial C_{M2}}{\partial a_{M2}} = p_2(q_1 + q_2) + \frac{\partial p_2}{\partial q_2} \cdot q_2 \tag{15}$$

which gives:

$$q_2 = q_2(q_1) \tag{16}$$

It follows from (12), (13) and (16) that p_1, p_2 and q_2 all are functions of the quotas sold in period 1.

The monopolist's optimization problem in period 1, given the fringe's demand functions for quotas, is given by:

$$\min_{q_1} \left\{ C_{M1}(a_{M1}) - p_1(q_1) \cdot q_1 + \delta \left[C_{M2}(a_{M2}) - p_2(q_1 + q_2(q_1)) \cdot q_2(q_1) \right] \right\} \tag{17}$$

Solving (17) and inserting from (11) and (15) gives the following first order condition:

$$\frac{\partial C_{M1}}{\partial a_{M1}} = p_1 + \frac{\partial p_1}{\partial q_1} \cdot q_1 - \delta p_2 \tag{18}$$

Let

$$q_1 = q_1^* \tag{19}$$

be the solution to (18).

From (7) - (10), (12), (13), (16) and (19) we find the amount of abatement in the two periods, the amount of quotas sold and the prices in period 1 and period 2 in the durable quota system, which we denote $a_{F1}^{DU*}, a_{F2}^{DU*}, a_{M1}^{DU*}, a_{M2}^{DU*}, q_1^{DU*}, q_2^{DU*}, p_1^{DU*}$ and p_2^{DU*}.[3]

[3] Superscript *DU* denotes the durable quota system.

Since the durable quota system puts restrictions on emissions within each sub-period, given by (1), a cost-effective distribution of abatement across periods, as expressed by (6), is generally not ensured. Furthermore, we see from (12) and (18), and (13) and (15) that the fringe's marginal abatement cost is higher than the monopolist's marginal abatement cost in both sub-periods, which means that (5) is not satisfied. The durable quota system does neither ensure cost-effectiveness across periods nor across countries.

2.2 A flexible quota system

In a flexible quota system each country decides how to allocate abatement between the two periods as long as total emissions do not exceed the total amount of quotas the country holds. The fringe's and the monopolist's total abatements over both periods are:

$$a_{F1} + a_{F2} = Z_{F1} + Z_{F2} - (Q_F^0 + Q) \tag{20}$$

and

$$a_{M1} + a_{M2} = Z_{M1} + Z_{M2} - (Q_F^0 - Q) \tag{21}$$

where Q is the total amount of quotas bought by the fringe.

The fringe will minimize the present value of the sum of the abatement costs in the two periods and the costs of buying quotas, given that its total emissions do not exceed the total amount of quotas hold. The fringe's optimization problem is:

$$\underset{a_{F1},a_{F2},Q}{\text{Min}} \left\{ C_{F1}(a_{F1}) + \delta C_{F2}(a_{F2}) + P \cdot Q \right\} \tag{22}$$

subject to (20).

First order conditions of this minimization problem are:

$$\frac{\partial C_{F1}}{\partial a_{F1}} = \delta \frac{\partial C_{F2}}{\partial a_{F2}} \tag{23}$$

and

$$P = \frac{\partial C_{F1}}{\partial a_{F1}}, \quad i = 1,2 \tag{24}$$

where *P* is the price of a quota in the flexible quota system.

Equation (23) states that the present value of the marginal abatement costs are equalized across periods (for all *Q*). Equations (23) and (24) give the inverse demand function for quotas (P(Q)).

The monopolist minimizes the present value of the sum of the abatement costs in the two periods minus the income from selling quotas given that its total emissions do not exceed the total amount of quotas hold, that is:

$$\underset{a_{M1},a_{M2},Q}{\text{Min}} \left\{ C_{M1}(a_{M1}) + \delta C_{M2}(a_{M2}) - P(Q) \cdot Q \right\} \tag{25}$$

subject to (21).

This gives the following first order conditions:

$$\frac{\partial C_{M1}}{\partial a_{M1}} = \delta \frac{\partial C_{M2}}{\partial a_{M2}} \tag{26}$$

and

$$\frac{\partial P}{\partial Q} \cdot Q + P = \frac{\partial C_{M1}}{\partial a_{M1}} \tag{27}$$

From equation (20), (21), (23), (24), (26) and (27) we obtain the amount of abatement in each period, the amount of quotas sold and the price of quotas in the flexible system which we denote $a_{F1}^{FL*}, a_{F2}^{FL*}, a_{M1}^{FL*}, a_{M2}^{FL*}, Q^*$ and P^*.[4]

---

[4] Superscript *FL* denotes the flexible quota system.

In a flexible quota system both the fringe and the monopolist will distribute abatement cost-effectively across periods, as can be seen from (23) and (26). However, we see from (24) and (27) that the fringe's marginal abatement cost will exceed the marginal abatement cost in the monopoly country in each period. The monopolist abates to little compared to a cost-effective distribution of abatement across countries due to its market power.

3. A comparison of the durable and the flexible quota system

In this section we compare the total cost of the two different systems of tradeable quotas. The present value of the total cost of the flexible quota system, denoted TC^{FL}, is given by:

$$TC^{FL} = \sum_{j=F,M} C_{j1}(a_{j1}^{FL*}) + \delta \sum_{j=F,M} C_{j2}(a_{j2}^{FL*}) \qquad (28)$$

The present value of the total cost of the durable quota system, denoted TC^{DU}, is given by:

$$TC^{DU} = \sum_{j=F,M} C_{j1}(a_{j1}^{DU*}) + \delta \sum_{j=F,M} C_{j2}(a_{j2}^{DU*}) \qquad (29)$$

A cost-effective quota system implies that the present value of marginal abatement costs for each period are equalized across countries and across periods, as expressed by (5) and (6). We know from the previous section that in the flexible quota system both the fringe and the monopolist distribute the abatement cost-effectively across periods, but that the fringe's marginal abatement cost exceeds the monopolist's marginal abatement cost in each sub-period. The monopolist sells too few quotas, and hence abate too little, compared to a cost-effective distribution of abatement across countries.

The deviation from a cost-effective distribution of abatement in the flexible quota system depends on the initial allocation of quotas. From the discussion in section 1 we know that the flexible quota system can result in a cost-effective distribution of abatement if the initial distribution of quotas is such that the "potential monopolist" finds it optimal to not sell any quotas. This means that the solution to the monopolist maximizing problem given by (27) gives Q* equal to 0. It then follows from (23), (24), (26) and (27) that the present value of marginal abatement costs for each period are equalized across countries and across periods. This implies that the quota system is cost-effective, as expressed by (5) and (6). Hence, if the initial distribution of quotas agreed on in the climate treaty, implies that Q* from (27) is zero, there is nothing to gain by changing from a flexible quota system to a durable quota system. On the contrary, the durable quota system will imply a higher total abatement cost, since that system implies that abatement is not distributed cost-effectively across periods.

However, if the initial distribution of quotas agreed on in the climate treaty implies that one of the countries acts as a monopolist in the quota market, the durable quota system may lead to lower total abatement cost than the flexible quota system, in spite of the non-optimal distribution of abatement over time. The reason for this is that a durable quota system can increase the total amount of abatement carried out by the monopolist, relative to the flexible quota system. In the flexible quota system, the quotas are only sold once, at time t_1. When deciding the optimal quantity of quotas offered for sale, the monopolist takes into account that an increase in the amount of quotas sold decreases the price on all units. However, in a durable quota system, where quotas are sold at two dates, t_1 and t_2, the amount of quotas sold at t_2 will not affect the price of the quotas sold at t_1. Those units are already sold, and once they are sold the monopolist has no interest in maintaining the price on those quotas. It is optimal for the monopolist to lower the quota price, that is, sell additional quotas, in period 2.. However, when the buyers correctly anticipate that the monopolist will reduce the price in the second period, less will be bought at a high price in the first period. In total this may lead to higher abatement in the monopolist country in the durable quota system, than in the flexible quota system.

As we pointed out in the previous section, a durable quota system does not ensure that abatement is distributed cost-effectively across periods within countries. Hence, more abatement in the monopolist country relative to the flexible quota system is not sufficient to ensure that the durable quota system is less costly than the flexible quota system. The durable quota system is less costly than the flexible quota system if the decrease in abatement cost due to higher abatement in the monopolist country is not completely offset by increased abatement cost due to a non-optimal distribution of abatement across periods.

Since the durable quota system puts restrictions on *emissions* within each sub-period, changes in the abatement costs (C(a)) and changes in the business as usual emissions (Z) over time will influence the cost of the durable quota system relative to the flexible quota system.

In order to make a further comparison of the two different quota systems we will first ignore the effects of changes in the abatement costs and business as usual emissions over time. (The impact of these changes will be discussed below.) Furthermore we assume that the marginal abatement costs are linear.[5]

We ignore the effects of changes in abatement costs and business as usual emissions over time by assuming that the present value of the abatement costs for each period do not change over time, that is $C_{j2}(a) = \frac{1}{\delta}C_{j1}(a)$, and that the business as usual emissions are identical in both periods for both categories of countries, that is $Z_{j1} = Z_{j2}$.[6] These assumptions ensure that the total abatement costs of the two systems are identical *before* any trade of quotas has taken place.

Let the fringe's abatement costs in period 1 and period 2 be given by:

---

[5] We have not been able to show the differences in total costs and abatements between a flexible and durable system analytically with non-linear marginal abatement costs. We have, however, carried out several numerical calculations on non-linear marginal cost functions without finding any cost functions where the conclusions we draw from linear marginal abatement costs do not hold.

[6] Assuming $C_{j2}(a) = \frac{1}{\delta}C_{j1}(a)$ is formally identical to assuming that the abatement cost functions are constant across periods if discounting is ignored, that is $\delta = 1$.

$$C_{F1}(a_{F1}) = \frac{1}{2}\beta \cdot (a_{F1})^2 + F \cdot a_{F1} \tag{30}$$

and

$$C_{F2}(a_{F2}) = \frac{1}{2\delta}\beta \cdot (a_{F2})^2 + \frac{1}{\delta} F \cdot a_{F2} \tag{31}$$

where δ is the discount factor and β and F are parameters in the abatement cost functions.

Let the monopolist's abatement costs in period 1 and period 2 be given by:

$$C_{M1}(a_{M1}) = \frac{1}{2}\theta \cdot (a_{M1})^2 + M \cdot a_{M1} \tag{32}$$

and

$$C_{M2}(a_{M2}) = \frac{1}{2\delta}\theta \cdot (a_{M2})^2 + \frac{1}{\delta} M \cdot a_{M2} \tag{33}$$

where δ is the discount factor and θ and M are parameters in the abatement cost functions.

From (7) - (10), (12), (13), (16), (19), (20), (21), (23), (24), (26) and (27) we find that the cost functions defined above give the following differences in abatement in the two quota systems:

$$a_{F1}^{*DU} - a_{F1}^{*FL} = -(a_{M1}^{*DU} - a_{M1}^{*FL}) = \frac{\varepsilon - \varphi}{\beta K(2+x)} \tag{34}$$

$$a_{F2}^{*DU} - a_{F2}^{*FL} = -(a_{M2}^{*DU} - a_{M2}^{*FL}) = -\frac{(\varepsilon - \varphi)(2+x)}{\beta K(2+x)} \tag{35}$$

where

$$\begin{aligned} &\varepsilon \equiv \beta\ (a_F^0) + F \quad \text{where } a_F^0 \equiv Z_F - q_F^0 \text{ and } q_F^0 = \tfrac{1}{2} Q_F^0 \\ &\varphi \equiv \theta(a_M^0) + M \quad \text{where } a_M^0 \equiv Z_M - q_M^0 \text{ and } q_M^0 = \tfrac{1}{2} Q_M^0 \\ &x \equiv \frac{\theta}{\beta} \\ &K \equiv 5 + 4x + x^2 \end{aligned} \tag{36}$$

The difference in total costs of the two quota systems is given by:

$$TC^{DU} - TC^{FL} = -\frac{1}{2}\frac{(\varepsilon-\varphi)^2(1+x)}{\beta K(2+x)^2} \quad < 0 \tag{37}$$

where TC^{FL} and TC^{DU} are defined by (28) and (29).

We see from the definitions in (36), that a_j^0 is the abatement in the flexible and durable quota system for country *j* before any trade of quotas has taken place. ε and φ are, respectively, the fringe's and monopolist's per period marginal abatement cost before trade occurs. We have assumed that the country which exercises market power is a seller of quotas. A necessary condition for sale is that $\varepsilon > \varphi$.

We see from (34) and (35) that the durable quota system causes the fringe (monopolist) to abate more (less) in period one and less (more) in period two compared to the flexible quota system. Furthermore, we see that the fringe's (monopolist's) total abatement over both periods is less (higher) in a durable quota system that in the flexible quota system. The durable quota system induces a transfer of abatement from the fringe to the monopolist compared to the flexible quota system. It follows from (37) that the total cost of the durable quota system is lower than the total cost of the flexible quota system. This means that the reduction in total cost due to higher abatement in the monopolist country is not completely offset by the increased cost due to a non-optimal distribution of abatement across periods.
Furthermore, we see from (37) that TC^{FL} -TC^{DU} (which is positive) is increasing in $(\varepsilon - \varphi)$. It follows from the definition of ε and φ, given by (36), that $(\varepsilon - \varphi)$ is higher the larger q_M^0 compared to q_F^0. Increasing q_M^0 relative to q_F^0 implies that the initial distribution of quotas deviates more from the cost-effective distribution of emissions (and hence abatement) across countries.

We have so far assumed that the country which exercises market power is a seller of quotas. If $\varepsilon < \varphi$, the country will buy quotas and hence be a monopsonist in the quota market. However, we see from (37), that the difference in cost of the two systems is independent on whether the country is a monopolist or a monopsonist. Furthermore, we see from (37) that a higher initial allocation of quotas to a monopsonist decreases the cost difference of the two quota systems since the absolute value of (ε–φ) is smaller the larger q_M^0 compared to q_F^0, when $\varepsilon < \varphi$. Increasing the initial allocation of quotas to a monopsonist implies that the initial distribution of quotas deviates less from the cost-effective distribution of abatement across countries.

This leads to the following conclusions *if* the marginal abatement costs are linear and the present value of the abatement cost for each period and the business as usual emissions do not change over time:

- The total abatement cost of a durable quota system is less than the total abatement cost of a flexible quota system.

-The more the initial allocation of quotas deviates from a cost-effective distribution of abatement across countries, the lower is the cost of the durable quota system compared to the flexible quota system.

For all abatement cost functions, changes in the abatement costs and changes in the business as usual emissions over time can increase the total cost of a durable quota system compared to the flexible quota system due to the lack of ability to allocate abatement optimally over time in the durable quota system. The more the restrictions on emissions in each sub-period in the durable quota system differ from the optimal distribution of abatement across periods, the higher is *cet. par.* the cost of the durable quota system compared to a flexible quota system.

As argued above, the flexible quota system is cost-effective if the initial distribution of quotes ensures that the “potential monopolist” finds it beneficial to not sell any quotas. An initial distribution of quotas which implies that the monopolist exercises market power will imply an efficiency loss because abatement is not distributed cost-effectively across countries. The more the durable quota system through reduced market power, reduces this efficiency loss, the lower is *cet par.* the cost of the durable quota system compared to a flexible quota system.

This leads to the following general conclusion:

-The difference in the total abatement costs between the durable and the flexible quota system can be negative or positive depending on the monopolist's market power in the flexible quota system and the changes in abatement costs and business as usual emissions over time.

We have so far assumed that the durable quota system specifies quotas which give the holder the right to emit the same quantity of CO_2 in each sub-period, that is σ in equation (1) is set to 0. However, by setting $\sigma \neq 0$, some of the disadvantages of the lack of flexibility of the durable quota system can be reduced. If, for instance, both the fringe's and the monopolist's present value of abatement costs per period decrease over time, the total cost of the durable quota system can be reduced by allowing higher emissions in period 1 than in period 2, that is, $0 < \sigma \leq 1$.

σ will have an impact on the trade in quotas since σ will influence fringe's and monopolist's marginal abatement costs in both sub-periods. The σ that minimizes the total cost is found by minimizing (29) with respect to σ where a_{ji}^{*DU} will be a function of σ. It is, however, in general not possible to completely remove the cost of a non-optimal distribution of abatement across periods by choosing an optimal σ. The σ that gives a cost-effective distribution of abatement across periods for the fringe will, in general, differ from the σ that gives an optimal distribution of abatement across periods for the monopolist. The reduction in the total cost of the durable quota system of choosing an optimal σ compared to a situation where σ is set to 0, depends on the changes in the monopolist's and the fringe's abatement costs and the business as usual emissions over time and the difference in these changes between the two categories of countries.

4.Numerical Illustrations

To illustrate the difference in total costs of obtaining a certain target for a total emissions reduction between a flexible and the durable quota system, we have carried out some numerical calculations. We have used the cost functions of reducing CO_2-emissions from Bohm and Larsen (1994) which are based on a study by Nordhaus (1991).[7] Bohm and Larsen's marginal cost functions fall into three categories separated by the size of the carbon intensities in different countries. A country with a carbon intensity equal to 0,26kg/USD is referred to as a *reference country* by Bohm and Larsen, and makes one of these categories. The two other categories of countries have carbon intensities above and below this level. Countries with lower carbon intensities than the *reference country* are supposed to have taken measures to reduce their carbon intensities, and their marginal abatement costs are higher than that of the *reference country*. The countries with higher carbon intensities than the *reference country* are supposed to have the lowest marginal abatement costs of all the three categories of countries. The cost and the marginal cost of reducing CO_2-emissions are increasing with the amount of CO_2 abated ($C'_{ji}(a_{ji}) > 0, C''_{ji}(a_{ji}) > 0$) and $C_{ji}(0) = 0$.

As discussed in the introduction, several countries could possibly exercise market power in the market of tradeable CO_2-quotas, among them the United States, China and Russia. In the numerical calculations carried out below, we consider a climate treaty where the Western European countries and China are the participating countries. China exercises monopoly power and faces a competitive fringe consisting of the Western European countries.

According to the United Nations' Framework Convention on Climate Change (FCCC) the developing country Parties of the convention shall not carry any of the costs of the measures to combat climate change (see article 4.3). It is thus unlikely that China in the near future is willing to participate in a climate treaty if this causes a financial loss. However, China has a high carbon intensity, and hence low abatement cost. The total

[7] Detailed discussions of the cost functions are given in Bohm and Larsen (1994).

cost of achieving a certain global goal for emissions reductions could therefore be significantly reduced if China would join the treaty. It can therefore be beneficial for the Western-Countries to compensate China for joining the treaty. One way of compensating China is through the initial allocation of quotas. The higher initial allocation of quotas that China receives, the more beneficial is it for China to join the treaty.

China has a carbon intensity of 1.6 kg/USD (World Resources, 1992 (1989 figures)), and falls in the category of countries with carbon intensities above that of the *reference country* (0,26kg/USD). It has the following marginal abatement cost function:

$$C'_{Mi}(a_{Mi}) = -185{,}2\ln\left(1-\frac{a_{Mi}}{Z_{Mi}}\frac{e_M}{(2e_M-\hat{e})}\right) \tag{38}$$

where e_M is the carbon intensity of China, and $\hat{e}$ is the *reference country's* carbon intensity.

To simplify we have used average values of carbon intensities and business as usual emissions in the Western-European countries to obtain one single abatement cost function. The Western-European countries (the fringe) have an average carbon intensity of 0.15kg/USD (Bohm and Larsen 1994, Table I). Their marginal cost function is as follows:

$$C'_{Fi}(a_{Fi}) = -185{,}2\ln\left(1-\frac{a_{Fi}}{Z_{Fi}}\frac{\hat{e}}{e_F}\right) \tag{39}$$

where e_F is the fringe's carbon intensity.

We assume that e_M, e_F and $\hat{e}$ do not change over time.

We have carried out the calculations under different assumptions of changes in business as usual emissions and different quota allocation systems. Opposed to the cost functions of the previous section (given by (30)-(33)) changes in business as usual emissions in the above marginal cost functions (given by (38) and (39)) will directly influence abatement costs since abatement costs are a function of relative abatement. The period length is ten years starting in year 2005 and divided into two equally long sub-periods of 5 years. We have based our emission scenarios on the Intergovernmental Panel on Climate Change's (IPCC) scenarios for greenhouse gas emissions (see IPCC 1996). The IPCC has developed six emission scenarios based on assumptions concerning population and economic growth, land use, technological changes, energy availability and fuel mix over the period 1990 to 2100.[8] In our calculations of the changes in business as usual emissions of CO_2 we have used three of these scenarios, IS92a, IS92c and IS92e.[9]

- Business as usual emissions change in line with the IS92a scenario. It implies a 15% and 1.8 % increase in the business as usual emissions from period 1 to period 2 in China and the Western-European countries, respectively.
- Business as usual emissions change in line with IS92c scenario, which implies a 7% increase and a 1.5% decrease in business as usual emissions from period 1 to period 2 in China and the Western-European countries, respectively.
- Business as usual emissions change in line with the IS92e scenario. It implies a 17% and a 4% increase from period 1 to period 2 in business as usual emissions in China and Western-European countries, respectively.

We have considered two different allocation rules. With the first allocation rule each country including China, receives quotas corresponding to 80 per cent of their business as usual emissions (BaU emissions). With the second allocation rule China receives quotas equal to its business as usual emissions and the Western-European countries receive quotas equal to business as usual emissions minus the target for emission (Q^0) (this allocation rule is called the special allocation rule). The latter allocation rule is an

[8] See Pepper et al. (1992) for a detailed description of the distribution of emissions across countries following from the different scenarios.

[9] The IS92c and IS92e assume the lowest and the highest CO_2-emissions respectively of the six scenarios in the report. The IS92a scenario is a mid-range scenario.

example of an allocation rule where China demands a high financial benefit in order to join the treaty.[10]

For both allocation rules we have calculated the total cost of the durable quota system with σ=0, and the total cost with an optimal σ (the impact of choosing an optimal σ has been discussed in the previous section).[11] The discount rate per year is 5%. This implies a discount factor (δ) of 0.78 for period 2. The results of the numerical calculations are presented in Table 1.

Table 1. The relative difference in total costs of the durable quota system compared to the flexible quota system.[12]

	Allocation rule: 80% of BAU		**Allocation rule: Special all.rule**	
Changes in costs from period 1 to period 2	Durable system with σ =0	Durable system with an optimal σ	Durable system with σ=0	Durable system with an optimal σ
BaU changes in line with the IS92a scenario	-0.31%	-0.36%	-5.55%	-5.64%
BaU changes in line with the IS92c scenario	0.36%	-1.23%	-4.42%	-8.59%
BaU changes in line with the IS92e scenario	-0.17%	-0.26%	-6.30%	-7.21%

The numerical calculations illustrate the following:

- For all the calculations except one, the durable quota system gives lower total cost than the flexible quota system. The gain from equalized marginal abatement costs

[10] The special allocation rule will more than offset what China needs to get compensated for its costs of reducing emissions (if they find it beneficial to sell any quotas). Although extreme, this allocation rule shows the effects of allocating more quotas to the monopoly country.

[11] Choosing an optimal σ implies that σ is endogenous in the calculations.

across periods in the flexible system, does not offset the gain from reduced effects of market power in the durable system. However, in the IS92c scenario with σ=0 and where the countries receive quotas corresponding to 80% of their business as usual emissions, the flexible quota system gives lower total costs than the durable quota system. In this case the gain from reduced effects of market power in the durable quota system is offset by the gain from equalized marginal abatement costs across periods in the flexible quota system.

- The introduction of an optimal σ in a durable quota system implies that marginal abatement costs across periods could be closer to the cost-effective solution compared to setting σ=0. Hence, the advantage of the durable quota system compared to the flexible quota system is increased. In our calculations the durable quota system with an optimal σ gives lower total cost than the flexible quota system for all the scenarios considered. As argued in the previous section, differences in the changes of business as usual emissions between countries implies that an optimal σ for one country is different from an optimal σ for the other. Hence, with differences in the changes in the business as usual emissions between countries we are not ensured that a common σ leads to lower total costs of the durable quota system than the flexible quota system. For all the scenarios considered in our calculations these differences are, however, not of such a magnitude that a common σ does not result in lower total cost of the durable quota system compared to the flexible quota system.

-The chosen allocation rule influences the advantage of the durable quota system compared to the flexible quota system. When quotas are allocated according to the special allocation rule, the cost of the durable quota system relatively to the flexible quota system is significantly decreased compared to an allocation of quotas in percentage of business as usual emissions. A higher initial allocation of quotas to the monopolist (monopsonist) as an allocation of quotas according to the special allocation rule will imply, increases (decreases) the deviation from a cost-effective distribution of

[12] The relative difference is computed in the following way: $\frac{TC^{DU} - TC^{FL}}{TC^{FL}}$. The durable quota

abatement across countries. This implies decreased (increased) cost of the durable quota system compared to the flexible quota system. Hence, if the monopolist (monopsonist) is compensated for joining an agreement through quota allocation, the advantage of the durable quota system compared to the flexible quota system is increased (decreased).

5.Concluding remarks.

When countries act strategically in the tradeable quota market there is no longer separability between considerations of effectiveness and considerations of equity, as would be the case in a competitive market for quotas. In this paper we have examined how the design of the quota system could reduce the efficiency loss from market power when the distribution of CO_2-quotas is restricted by equity considerations. We have compared two different tradeable quota systems - a durable quota system and a flexible quota system. A durable quota system can reduce the adverse effects of market power. However, it sets restrictions on the sum of emissions from the fringe and the monopolist in each sub period. This implies that a durable quota system does not ensure an optimal distribution of abatement across periods. In a flexible quota system we obtain an optimal distribution of abatement across periods. However, due to the monopolist's market power the difference in marginal abatement costs across countries could be higher compared to a durable quota system. Hence, we face a trade-off between a cost-effective distribution of abatement across periods and reduced adverse effects of market power. The durable quota system is less costly than the flexible quota system if the decrease in abatement cost due to higher abatement in the monopolist country is not completely offset by increased cost due to a non-optimal distribution of abatement across periods.

We have shown that if the present value of abatement costs for each period do not change over time, business as usual emissions remain unchanged and marginal abatement costs are linear:

---

system is less costly than the flexible quota system when the relative difference is negative.

- The total abatement cost of a durable quota system is less than the total abatement cost of a flexible quota system.
- The more the initial allocation of quotas deviates from a cost-effective distribution of abatement across countries, the lower is the cost of the durable quota system compared to the flexible quota system.

In general, changes in abatement costs and changes in the business as usual emissions over time can increase the total cost of a durable quota system compared to a flexible quota system. As a result the difference in total abatement costs between the durable and the flexible quota system can turn out to be both negative or positive depending on the monopolist's market power in the flexible quota system and the changes in abatement costs and business as usual emissions over time.

In the last part of the paper we have carried out numerical calculations of the cost differences between the durable and the flexible quota system. They are carried out with increasing and convex cost functions, and clearly illustrate that the advantage of the durable quota system compared to the flexible quota system depends on the chosen allocation rule. With the use of the special allocation rule, which implies that the monopoly country receives quotas equal to its business as usual emissions, the advantage of durable quota system is increased considerably compared to an allocation rule where countries receive quotas equal to 80 per cent of their business as usual emissions.

We have assumed that the participants only trade quotas at time t_1 and t_2. Coase (1972) conjectured and Gul, Sonnenschein and Wilson (1986) showed formally that a durable monopolist that produces an infinitely durable good must always charge the competitive price as the time between offers approaches zero. Why could we not design the durable quota system in such a way that quotas are offered arbitrarily frequently to make the market power vanish, and reach the competitive outcome? The monitoring costs prevent this. Monitoring that emissions are in compliance with the total amount of quotas held would also have to be done arbitrarily frequently. Apart from the practical problems of carrying out such an intensive control (which most likely would be impossible to carry out), the costs of doing it would also be enormous. Therefore, what Coase conjectured is not possible to achieve in a durable quota system. Market power can be reduced by making the quotas durable, but it cannot be reduced to zero. It is impossible to make the period length arbitrarily small.

We have only considered one large seller. Gul (1987) and Ausubel and Deneckere (1987) show that letting the firms in a durable goods oligopoly make offers arbitrarily frequently with infinite durability enhances their ability to commit to high prices, and in the limit when the period length approaches zero, enables them to enjoy total market profit equal to the full commitment monopoly profit. There could obviously be possibilities for several agents with market power in a tradeable quota system. However, the results of Gul (1987) and Ausubel and Deneckere (1987) rely on infinite durability and arbitrarily frequent offers. As discussed above arbitrarily frequent offers are impossible in a durable quota system because of monitoring costs, but in addition their results are no longer valid in a finite horizon game as the one we study. It is a well-known result from the literature of game theory that it is possible to sustain a tacit collusion in an infinite repeated game. However, in a finite horizon game it would be profitable for the oligopolist to sell/ buy quotas at a lower price than the oligopoly price in the last period. The other oligopolists and the consumers know this. The commitment is no longer credible. By use of backward induction, we end up in a situation where the market power of the oligopolists is reduced as under durable good monopoly.

It can be argued that if we design the system such that there are only price-taking traders operating in the market of tradeable quotas, the problem discussed in this paper would disappear. Why not let each producer and importer of fossil fuels to a country operate in the tradeable quota market rather than countries? There are several reasons why this would not make the market competitive. First, many of the importers and the producers of fossil fuels would probably have the possibility of acting strategically in the quota market as well. Many of them have large market shares. The market power problem could be reduced, but it would probably not disappear. Second, if a country has the ability to act strategically when countries are traders in the quota market, it can still act strategically if its importers and producers of fossil fuels are traders of quotas.

By introducing national taxes on fossil fuels it can affect the supply or demand of quotas in the international market of tradeable CO_2-quotas, and hence be able to exercise market power as before.

In the literature of durable goods it is shown that the durable quota monopolist could escape the "trap" of durability by leasing the quotas and enjoy the full effects of market power. (See for instance Coase (1972) for a discussion of this issue.) To avoid this the durable quota system has to be designed in such a way that leasing is not possible. If a quota exchange for tradeable durable quotas is established, and only the traded quotas on the exchange are approved by a control commission in the monitoring of emissions, we cannot see that a leasing market would arise. It will not be profitable to lease a quota outside the exchange system since a leased quota not approved by the commission, has no value for the holder.

References

Ausubel, L.M. and R.J. Deneckere (1987), One is almost enough for Monopoly, *Rand Journal of Economics* 18, 255-274.

Bohm, P. and B. Larsen (1994), Fairness in a Tradeable-permit Treaty for Carbon Emissions Reductions in Europe and the Former Soviet Union, *Environmental and Resource Economics* 4, No. 3.

Coase R. H. (1972), Durability and Monopoly, *Journal of Law and Economics* 15, 143-149.

Hahn, R. W. (1984), Market Power and Transferable Property Rights, *Quarterly Journal of Economics* 99, 753-765.

Gul, F. (1987), Noncooperative Collusion in a Durable Goods Oligopoly, *Rand Journal of Economics* 18, 248-254.

Gul, F., H. Sonnenschein and R. Wilson (1986), Foundations of Dynamic Monopoly and the Coase Conjecture, *Journal of Economic Theory* 39, 155-190.

IPCC (1996), *Climate Change 1995 - Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*, Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change, R.T. Watson, M.C. Zinyowera and R.H. Moss (Eds.), Cambridge University Press.

Pepper W., J. Leggett, R. Swart, J. Wasson, J. Edmonds and I. Mintzer (1992), Emission Scenarios for the IPCC. An Update, Prepared by for the Intergovernmental Panel on Climate Change, Working Group 1.

Mongomery, D.W. (1972), Markets in Licenses and Efficient Pollution Control Programs, *Journal of Economic Theory* 5, 395-418.

Nordhaus, W.D. (1991), The Cost of Slowing Climate Change: a Survey, *The Energy Journal* 12, 37-65.

Tirole, J. (1988), *The Theory of Industrial Organization*, The MIT Press.

Westskog, H. (1996), Market Power in a System of Tradeable CO_2-quotas, *The Energy Journal* 17, 85-103.

World Resource Institute (1992), *World Resources 1992-1993,* Oxford University Press, Oxford.

World Resource Institute (1996), *World Resources 1996-1997,* Oxford University Press, Oxford.

This is CICERO

CICERO was established by the Norwegian government in April 1990 as a non-profit organization associated with the University of Oslo.

The research concentrates on:

- International negotiations on climate agreements. The themes of the negotiations are distribution of costs and benefits, information and institutions.

- Global climate and regional environment effects in developing and industrialized countries. Integrated assessments include sustainable energy use and production, and optimal environmental and resource management.

- Indirect effects of emissions and feedback mechanisms in the climate system as a result of chemical processes in the atmosphere.

Contact details:

CICERO
P.O. Box. 1129 Blindern
N-0317 OSLO
NORWAY

Telephone: +47 22 85 87 50
Fax: +47 22 85 87 51
Web: www.cicero.uio.no
E-mail: admin@cicero.uio.no