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Dominant agents and intertemporal emissions trading

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Sammendrag:
I denne artikkelen analyserer vi hvordan en restriksjon på lån av utslippskvoter mellom perioder kan gi en dominerende aktør økte muligheter til å utnytte markedsmakten sin. Vi ser også på hvilke konsekvenser dette har for kostnadseffektiviteten av å nå et utslippsmål. I artikkelen viser vi at en monopolist kan utnytte en restriksjon på lån av kvoter til sin fordel gjennom å fordele salg av kvoter ineffektivt mellom perioder. Den ineffektiviteten som oppstår påvirkes imidlertid av hvordan man allokerer kvoter mellom aktørene initialt sett. En kostnadseffektiv fordeling av utslippsreduksjoner over perioder kan oppnås med en passende fordeling av de totale utslippsreduksjonene over tid for hver aktør.

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Abstract:
In this paper we analyze how restricting intertemporal trading by prohibiting borrowing of emission permits affects the ability of a dominant agent to exploit its market power, and the consequences this has for the cost-effectiveness of implementing an emissions target. We show that the monopolist could take advantage of the constraint on borrowing by distributing the sale of permits ineffectively across periods, and moreover that this inefficiency is influenced by the way permits are initially allocated between agents. A cost-effective distribution of abatement across periods can be achieved by an appropriate distribution of the total endowments of permits over time for each agent.

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1 Introduction

In this paper we analyze how restricting intertemporal trading by prohibiting the borrowing of emission permits affects the ability of a dominant agent to exploit its market power, and the consequences this has for the cost-effectiveness of implementing an emission target. Hence, we are asking whether the constraint on borrowing makes it possible for the dominant agent to increase its profit by distributing sales cost-ineffectively across periods. Further, we discuss how the initial allocation of emission permits influences this possibility.

Several intertemporal trading mechanisms prohibit borrowing because it provides no guarantee that the emissions borrowed will be abated in the future. Firms may shut down in future periods such that their borrowed emissions are not abated. Further, with international agreements one also faces the danger of changed policies towards a participation in international agreements, which might lead to that a country withdraws from an agreement and hence that their borrowed emissions are not paid back. In the United States, only banking of tradable sulfur dioxide permits is allowed. (EPA 2003). Further, California's Low-Emission Vehicle Program allows manufacturers of passenger cars only to bank, not borrow, hydrocarbon emissions (California Air Resource Board 2003). At the international level, the Kyoto Protocol allows banking of emission permits between periods, but not borrowing.

Equity issues or political conditions will often play a role in allocating permits among various agents in an emission trading system. These considerations could result in a distribution of permits that gives some firms or countries an opportunity to exercise market power in the emission permits market.[1] For instance, under the Kyoto Protocol, Russia is allocated a large amount of permits for the period from 2008 to 2012, and it is expected to be large seller of permits (see e.g. Weyant and Hill 1999).[2]

Hagem and Westskog (1998) look at the linkage between intertemporal emissions trading and exercising of market power in the emissions permit market. They show that with full intertemporal trading, costs will be minimized across periods, even if there is an agent that exercises market power in the emissions permit market. However, inefficiencies across agents will occur because of the exercising of market power. This paper focuses on another important element of the linkage between intertemporal trading and exercising of market power, namely how restrictions on intertemporal trading affect the inefficiencies caused by a dominant agent. We argue that prohibiting borrowing combined with agents that exercise market power has consequences for the market outcome, the effectiveness of the system, and how emissions permits should be allocated across periods for each agent to reduce the inefficiencies caused by the dominant agent.

Introducing a constraint on borrowing allows a dominant agent to manipulate the price difference across periods. From the literature of third-degree price discrimination, we know that the monopolist can profit from price discrimination when the markets can be separated

[1] Hahn (1984) shows that the opportunities for an agent to exercise market power could be undermined (i.e. the cost-effective outcome is achieved) by an appropriate distribution of permits between agents. However, this result depends on there being no other considerations that influence the decision of how permits should be allocated. Equity or political considerations play no role. Our paper is written under the assumption that a regulator must take equity considerations or political issues into account when deciding how permits should be allocated between agents, and hence that this could result in a distribution of permits where some dominant agents exercise market power.

[2] The presence of market power in a permit market has been widely discussed and analyzed in connection with the implementation of the Kyoto Protocol. Westskog (1996) and Böhringer and Löschel (2003) analyze a situation where market power is exercised on the supply side of the permit market.

(see for instance Varian 2003). However, our problem differs somewhat from this literature. A constraint on borrowing allows only one-way price discrimination, which implies that the present value price of permits could decrease over time in equilibrium, but not the other way around due to the possibility for arbitrage. The literature on third degree price discrimination generally assumes complete separation between the markets. Further, in our problem the costs of abatement – i.e. the costs of producing permits for sale for the monopolist – could differ between periods due to the constraint on borrowing. The standard assumption in the literature of third degree price discrimination is that the costs of producing goods for each market are identical. Hence, in this paper we deviate from the traditional assumptions within the analyses of third degree price discrimination by analyzing a problem with one-way price discrimination and potentially different costs of producing permits between markets (i.e. periods). The paper is organized as follows: First, section 2 investigates whether the constraint on borrowing induces the dominant agent to increase its profit by distributing its total sale of permits cost-ineffectively across periods. Second, section 3 analyzes how the initial intertemporal distribution of permits for each agent influences the possibility of a dominant agent to exercise market power under a constraint on borrowing. Further, we consider a special case in section 4, with a competitive market in future periods and a dominant agent in the first. Finally, section 5 discusses how the constraint on borrowing affects the total sale of quotas from the dominant agent.

In this paper, we show that the monopolist could take advantage of the constraint on borrowing by distributing sales of permits ineffectively across periods. This could be the case with both a decreasing present value price of permits over time and when the present value price is constant. Hence, observing a constant present value price of permits over time, does not necessarily imply a cost-effective distribution of abatement across periods. Further, this inefficiency is influenced by the way permits are distributed across periods for each agent. We show that the regulator can ensure a cost-effective distribution of abatement across periods by an appropriate distribution of each agent's total endowment of permits over time.

2 The model

To show the key idea of our paper, it is sufficient to use a two-period model (the present period and the future period) for a tradable permit system. There is one dominant agent in the permit market. We will in the following assume that this agent is a large seller of permits, and is hereafter referred to as the monopolist, and denoted M.[3] All other agents are such small buyers or sellers that they are considered to be price takers. These are referred to as the fringe and denoted F. The fringe is in total net buyers of permits.

The agents are initially allocated an endowment of permits for each period Q_{ij}^0, where i denotes the period (i = 1,2) and j denotes the agents (j=F,M). The agents can freely trade permits with each other within each period. We compare two different intertemporal trading regimes - one where the agents can freely bank and borrow permits across periods, and one where the agents are allowed to bank permits, but not borrow. We refer to the first as the "full intertemporal trading regime" and the latter as the "restricted intertemporal trading regime."

[3] The general conclusions of the paper are not affected whether we have a monopolist or a monopsonist.

Under both systems, the agents are obliged to ensure that their total emissions across both periods do not exceed the sum of held permits over both periods. The sum of held permits is the amount of quotas allocated in both periods plus/minus the quotas they buy/sell. Hence, the total emission constraint for the fringe and monopolist are given by, respectively

$$e_{1F} + e_{2F} = Q^0_{1F} + Q^0_{2F} + q_1 + q_2 \qquad (1)$$

$$e_{1M} + e_{2M} = Q^0_{1M} + Q^0_{2M} - (q_1 + q_2) \qquad (2)$$

Where e_{ij} is emissions in period *i* by agent *j*, and q_i is sale the amount of bought in period *i*.

Under the restricted intertemporal trading regime, the agents are not allowed to borrow permits, which means that their emissions in period 1 cannot exceed the number of permits they hold in that period. The non-borrowing constraints are given by

$$Q^0_{1F} + q_1 - e_{1F} \geq 0 \qquad (3)$$

$$Q^0_{1M} - q_1 - e_{1M} \geq 0 \qquad (4)$$

There are no restrictions on banking, so excess permits from period 1 can be transferred to period 2.

Let $C_{ij}(e_{ij})$ define the abatement cost function for agent *j* in period *i*[4]. We assume that $C_{ij}(e_{ij})$ are twice continuously differentiable. The marginal abatement costs, $(-\frac{\partial C_{ij}(e_{ij})}{\partial e_{ij}})$, are positive and strictly increasing, that is $(\frac{\partial C_{ij}(e_{ij})}{\partial e_{ij}} < 0$ and $\frac{\partial^2 C_{ij}(e_{ij})}{\partial^2 e_{ij}} > 0)$. We assume that the agents have perfect information about each other's cost functions, and perfect foresight about future permit prices.

2.1 Conditions for cost-effectiveness

Given no constraints on banking or borrowing – i.e., a constraint only on total emissions – a cost-minimizing allocation of abatement between agents and across periods is achieved when the present value of marginal abatement costs between agents and across periods is equalized (see e.g. Tietenberg (1985)). With a restriction on borrowing, cost-effectiveness would still mean that marginal abatement costs across agents should be equalized. However, there is a shadow cost that follows from the non-borrowing constraint. A positive shadow cost implies that there is a difference in marginal abatement costs across periods. With a constraint on borrowing, a necessary condition for cost-effectiveness , is that the difference in marginal abatement costs is equalized across periods for each agent (See Rubin (1996)). This implies that the positive shadow cost following from the non-borrowing constraint is equal for all

[4] Note that emissions for agent *j* in period i (e_{ij}) are equal to the business as usual emissions that the agent has in period *i* minus the abatement the agent carries out during the same period (a_{ij}). This implies that the marginal abatement costs for agent *j* in period *i*, i.e. $\frac{\partial C_{ij}(a_{ij})}{\partial a_{ij}}$, is equal to $-\frac{\partial C_{ij}(e_{ij})}{\partial e_{ij}}$.

agents. We see this by minimizing the total cost for agents with respect to their emissions in each period, given their emission reduction requirements and the non-borrowing constraint:

$$\underset{e_{1F},e_{2F},e_{1M},e_{2M}}{Min} \quad TC = \left[C_{1F}(e_{1F}) + \delta C_{2F}(e_{2F}) + C_{1M}(e_{1M}) + \delta C_{2M}(e_{2M})\right] \tag{5}$$

s.t $\quad e_{1F} + e_{2F} + e_{1M} + e_{2M} = Q^0_{1F} + Q^0_{2F} + Q^0_{1M} + Q^0_{2M} \qquad (6)$

and $\quad Q^0_{1F} + Q^0_{1M} - e_{1F} - e_{1M} \geq 0 \qquad (7)$[5]

The solution to this problem is characterized by

$$-\frac{\partial C_{iF}(e_{1F})}{\partial e_{iF}} = -\frac{\partial C_{iM}(e_{iM})}{\partial e_{iM}} \quad i = 1,2 \tag{8}$$

$$-\frac{\partial C_{1F}(e_{1F})}{\partial e_{1F}} - (-\delta \frac{\partial C_{2F}(e_{2F})}{\partial e_{2F}}) = -\frac{\partial C_{1M}(e_{1M})}{\partial e_{1M}} - (-\delta \frac{\partial C_{2M}(e_{2M})}{\partial e_{2M}}) \qquad (9)$$[6]

and

$$-\frac{\partial C_{1j}(e_{1j})}{\partial e_{1j}} - (-\delta \frac{\partial C_{2j}(e_{2j})}{\partial e_{2j}}) = \lambda_2 \quad j = F, M \tag{10}$$

where

δ is the discount factor and λ_2 is the shadow cost of the non-borrowing constraint given by:

$$\lambda_2 \geq 0 \quad (= 0 \; if \; Q^0_{1F} + Q^0_{1M} - e_{1F} - e_{1M} > 0) \tag{11}$$

This confirms the claims above.

Hence, cost effectiveness implies that marginal abatement costs are equalized across agents within each period (eq. (8)), and that the difference in marginal abatement costs across periods is identical for both agents (eq. (9)), and equal to the shadow cost of the non-borrowing constraint (eq.(10)). We henceforth refer to eq. (9) as the intertemporal cost-effectiveness condition. In the next section we show how restrictions on borrowing may lead to situations where this condition will not be satisfied.

2.2 Prohibiting borrowing

In this section we examine whether prohibiting borrowing may induce the monopolist to manipulate with the difference in permit prices over time to its own advantage. With full intertemporal trading, Hagem and Westskog (1998) showed that although monopoly implies cost-ineffectiveness between agents within each period, cost-effectiveness across periods will be achieved. With full intertemporal trading the present value price of quotas will be equalized across periods even with monopoly. If not, there would be room for intertemporal arbitrage (see Hagem and Westskog op.cit. for proof). Hence, the monopolist would not be able to manipulate prices over periods.

[5] Observe that restrictions (1) and (2) correspond to (6), and that (3) and (4) correspond to (7).

[6] Equation (9) follows from (8), and is included because we refer to this condition in the following analyses.

However, prohibiting borrowing implies a one-way separation of the permit market. The monopolist may take advantage of this one-way separation of the two periods. This establishes a price difference over time that does not lead to intertemporal cost effectiveness, as defined in eq. (9). We first derive the fringe's demand functions for permits, found from the solution to the fringe's optimization problem. Given this demand function we could find the monopolist's choice of permit sale over time.

2.2.1 The fringe's optimizing problem

The optimizing problem for the fringe is given by:

$$\max_{q_{1F},q_{2F},e_{1F},e_{2F}} \Pi_F = -p_1 \cdot q_1 - C_{1F}(e_{1F}) - \delta\left[p_2 \cdot q_2 + C_{2F}(e_{2F})\right] \qquad (12)$$

subject to the total emission constraint, given by (1), and the non-borrowing constraint, given by (3), where p_i denotes the permit price in period *i,* and δ is the discount factor.

The first order conditions for the optimization problem are given by:

$$p_1 = -\frac{\partial C_{1F}(e_{1F})}{\partial e_{1F}} \qquad (13)$$

$$p_2 = -\frac{\partial C_{2F}(e_{2F})}{\partial e_{2F}} \qquad (14)$$

and

$$p_1 = \delta p_2 + \lambda_F \qquad (15)$$

$$\lambda_F \geq 0 \quad (= 0 \; if \; Q_{1F}^0 + q_{1F} - e_{1F} > 0) \qquad (16)$$

Where λ_F is the shadow cost of the non-borrowing constraint.

Let e_{1F}^* and e_{2F}^* denote the solution to (13) and (14).

Consider first a situation where the constraint on borrowing is non-binding for the fringe in equilibrium. In this situation λ_F is equal to zero, and we see that in this case, the present value price of permits would be equal across periods. The equilibrium conditions for the case where the non-borrowing constraint is non-binding correspond to a situation with full intertemporal trading. With full intertemporal trading, the present value price of permits is equalized across periods in equilibrium. In this situation the permit price is a function of the total amount of permits bought over both periods (Hagem and Westskog op.cit.). Thus, λ_F =0, leads to the following;

$$p_1 = \delta p_2 = p(q_1 + q_2) \qquad for \quad \lambda_F = 0 \qquad (17)$$

However, if the non-borrowing constraint is binding, the present value price of permits would be non-increasing over time; $p_1 \geq \delta p_2$. This implies that (3) is satisfied with equality. It then follows from (1), that the fringe faces a per-period emissions constraint given by:

$$Q_{1F}^0 + q_{1F} - e_{1F} = 0 \qquad (18)$$

$$Q_{2F}^0 + q_{2F} - e_{2F} = 0 \qquad (19)$$

When the non-borrowing constraint is binding, we see from (13), (14), (18) and (19) that the price of permits in each period is a function of permit sale in that period (since e^*_{1F} and e^*_{2F} are functions of q_{1F} and q_{2F} respectively):

$$p_1 = p_1(q_1) \quad (20)$$

$$p_2 = p_2(q_2) \quad (21)$$

It follows from our assumptions about the abatement cost functions that the prices decrease as the quantity sold increases:

$$\frac{\partial p_1}{\partial q_1} = -\frac{\partial^2 C_{1F}}{(\partial e^*_{1F})^2} < 0. \quad (22)$$

$$\frac{\partial p_2}{\partial q_2} = -\frac{\partial^2 C_{2F}}{(\partial e^*_{2F})^2} < 0. \quad (23)[7]$$

2.2.2 The monopolist's optimizing problem

When there is a constraint on borrowing, the monopolist's problem is no longer only to choose its optimal number of permits sold over both periods, but also the distribution of sales across periods. As discussed above, this may lead to both cost-ineffectiveness across agents (eq. (8) is violated) and cost-ineffectiveness across periods (eq. (9) is violated). To focus on the non-borrowing constraint's impact on intertemporal cost-effectiveness when there is a monopolist in the permit market, we derive the monopolist distribution of permit sales for a given total sale of permits. The effects of reduced or increased total sales of permits are hence not included. These effects would be important to incorporate in the discussion of the effects on total costs of the constraint compared to a situation with full intertemporal trading. We discuss this in section 5.

Let $\overline{Q}$ $(= q_1 + q_2)$ denote the given total sale of permits over both periods. Whether the non-borrowing constraint becomes binding for the fringe can be determined by the monopolist's distribution of total permit sales across periods. For any given total sale of permits, the monopolist can make the non-borrowing constraint binding by selling sufficiently few of the permits in period 1 (unless the non-borrowing constraint is not binding even for $q_1 = 0$). A binding constraint for the fringe implies that the monopolist can get a higher present value price for the permits in period 1 than in period 2. However, because banking is permitted, the monopolist cannot force the present value price in period 2 above the price in period 1 by selling sufficiently many permits in period 1.

Let $\tilde{q}_{1F} = \tilde{q}_{1F}(\overline{Q})$ denote the maximum number of permits sold by the monopolist in period 1, which makes the non-borrowing constraint binding for the fringe. Hence, for $q_{1F} > \tilde{q}_{1F}$, the non-borrowing constraint is not binding for the fringe, that is $\lambda_F = 0$ for $q_1 > \tilde{q}_{1F}$ (and then the present value price of permits is a function of the total permit sales; $p_1 = \partial p_2 = p(q_1 + q_2)$, and will be identical across periods). On the other hand, if $q_{1F} \le \tilde{q}_{1F}$, the fringe faces a binding non-borrowing constraint, and the price functions are given by

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[7] From equations (18) and (19) we have: $\frac{\partial e^*_{1F}}{\partial q_1} = 1$ and $\frac{\partial e^*_{2F}}{\partial q_2} = 1$.

$p_1 = p_1(q_1)$ and $p_2 = p_2(q_2)$. In this case we see from the characteristics of the price functions ((22)- (23)) that the present value price of permits would decrease over time, i.e. $p_1 > \delta p_2$ and $\lambda_F > 0$ for $q_{1F} < \tilde{q}_{1F}$ .When $q_{1F} = \tilde{q}_{1F}$, the present value price of permits would be identical across periods, i.e. $p_1(q_1) = \delta p_2(q_2)$ and $\lambda_F = 0$.

In order to derive the monopolist's distribution of permit sale over time it can be useful to divide the monopolist profit maximizing problem in two steps. The monopolist's optimizing problem is to find the optimal distribution of emission over time, in addition to the optimal distribution of permit sale over time. In the following we first derive conditions for the distribution of emission over time, and show that the optimal distribution of emissions over time is a function of the distribution of permit sale over time. Hence, we can express the monopolists' profit as a function of the distribution of permit sale only (given that emission is optimally distributed across periods).

Optimal distribution of emissions over time implies that the total abatement cost is minimized. This leads to the following optimizing problem

$$\min_{e_{1M},e_{2M}} TC_M(e_{1M},e_{2M}) = C_{1M}(e_{1M}) + \delta\left[C_{2M}(e_{2M})\right] \qquad (24)$$

s.t.

$$q_{1M} + e_{1M} - Q_{1M}^0 \leq 0 \qquad (25)$$

$$e_{1M} + e_{2M} = Q_{1M}^0 + Q_{2M}^0 - \overline{Q} \qquad (26)$$

This leads to the following first-order conditions

$$-\frac{\partial C_{1M}}{\partial e_{1M}} - (-\delta \cdot \frac{\partial C_{2M}}{\partial e_{2M}}) - \lambda_M = 0 \qquad (27)$$

$$\lambda_M \geq 0 \quad (= 0 \; if \; q_1 + e_{1M} < Q_{1M}^0) \qquad (28)$$

We see from (27) and (28) that the difference in the present value of the marginal abatement costs over time equals the shadow cost of the non-borrowing constraint. Whether the non-borrowing constraint becomes binding depends on the distribution of permit sale across periods. If the non-borrowing constraint is binding for the monopolist, the monopolist's emissions in each period are functions of the first-period sale (q_1).

Let $e_{1M}^*(q_1)$ and $e_{2M}^*(q_1)$ denote the solution to (27) and (28). Furthermore, let $\tilde{q}_{1M} = \tilde{q}_{1M}(\overline{Q})$ denote the maximum number of permits the monopolist can sell without facing a binding non-borrowing constraint. This implies that, $\lambda_M = 0$ for $q_1 \leq \tilde{q}_{1M}$, and hence that $-\frac{\partial C_{1M}}{\partial e_{1M}^*} = -\delta \cdot \frac{\partial C_{2M}}{\partial e_{2M}^*}$, for $q_1 \leq \tilde{q}_{1M}$.

The monopolist profit maximizing distribution of a given total permit sale over time, ($\overline{Q}$), can now be found by

$$\max_{q_1} \Pi_M(q_1) = p_1 \cdot q_1 - C_{1M}(e^*_{2M}(q_1)) + \delta\left[p_2 \cdot (\bar{Q} - q_1) - C_{2M}(e^*_{2M}(q_1))\right] \tag{29}$$

s.t.

$$\begin{aligned} &p_1 = p_1(q_1) \quad and \quad p_2 = p_2(q_2) \quad for\ q_1 \le \tilde{q}_{1F} \\ &p_1 = \delta p_1 = p(\bar{Q}) \quad for\ q_1 > \tilde{q}_{1F} \end{aligned} \tag{30}$$

We find the following first-order condition for an interior maximum:

$$\begin{aligned} p_1 + \frac{\partial p_1}{\partial q_1} \cdot q_1 - \delta \cdot \left(p_2 + \frac{\partial p_2}{\partial q_2} \cdot q_2 \right) + \left(\frac{\partial C_{1M}}{\partial e^*_{1M}} - \delta \cdot \frac{\partial C_{2M}}{\partial e^*_{2M}}\right) \cdot \frac{\partial e^*_{1M}}{\partial q_1} = 0 \quad for\ \ q_1 \le \tilde{q}_{1F} \\ \left(\frac{\partial C_{1M}}{\partial e^*_{1M}} - \delta \cdot \frac{\partial C_{2M}}{\partial e^*_{2M}}\right) \cdot \frac{\partial e^*_{1M}}{\partial q_1} = 0 \quad for\ \ q_1 > \tilde{q}_{1F} \end{aligned} \tag{31}$$

where it follows from (27) and (28) that

$$\begin{aligned} &\frac{\partial e^*_{1M}}{\partial q_1}\left(= -\frac{\partial e^*_{2M}}{\partial q_2}\right) = 0 \quad for \quad q_1 \le \tilde{q}_{1M} \\ &\frac{\partial e^*_{1M}}{\partial q_1}\left(= -\frac{\partial e^*_{2M}}{\partial q_2}\right) = 1 \quad for \quad q_1 > \tilde{q}_{1M} \end{aligned}$$

Since the price functions change for $q_1 = \tilde{q}_{1F}$ due to the non-borrowing constraint, the marginal profit function is discontinues for $q_1 = \tilde{q}_{1F}$. This implies that the first order conditions can be satisfied for q_1 both larger and less than $\tilde{q}_{1F}$. Furthermore, the solution to the maximizing problem may also be a corner solution where there is no q_1 which satisfies the first order conditions.

We find tree different solutions to the first order condition and one possible corner solution:

i) The first-order condition, (31), is satisfied for $q_1 \le \tilde{q}_{1F}$, while there is no $q_1 > \tilde{q}_{1F}$ which satisfies (31). In this case we have a unique interior solution.

ii) The first-order condition is satisfied both for a specific $q_1 \le \tilde{q}_{1F}$ and for a range of $q_1 > \tilde{q}_{1F}$.

iii) The first order condition is satisfied for a range of $q_1 > \tilde{q}_{1F}$, while there is no $q_1 \le \tilde{q}_{1F}$ which satisfies the condition.

iv) Neither $q_1 \le \tilde{q}_{1F}$ nor $q_1 > \tilde{q}_{1F}$ satisfies the first-order condition. This results in a corner solution.

In order to find a global maximum of the monopolist profit function we will in the following assume that marginal revenue from permit sale in period 1 is a decreasing function of permit sale for all $q_1 \le \tilde{q}_{1F}$ [8]. This implies that the monopolist's marginal profit function, $\frac{\partial \Pi_M(\overline{Q}, q_1)}{\partial q_1}$, is decreasing in quantities for all $q_1 \le \tilde{q}_{1F}$, it is discontinuous for $q_1 = \tilde{q}_{1F}$, it is negative or zero for $q_1 > \tilde{q}_{1F}$ and it is kinked at $q_1 = \tilde{q}_{1M}$. [9] To illustrate the possible outcomes of the monopolist's maximization problem we draw the different paths for the marginal profit function This function, denoted $\frac{\partial \Pi_M(\overline{Q}, q_1)}{\partial q_1}$, is expressed by the left hand side of (31).

Examples of different paths for the marginal profit function described by the alternatives *i) – iv)* above, are drawn in figure 1 – 4. From the figures, we see that there are three possible solutions to the monopolist's profit maximizing problem:

1. When the first order conditions are satisfied for , $q_1 \le \tilde{q}_{1F}$, we obtain a unique solution for the optimal q_1, denoted q_1^*. Hence, in both situation i) and ii) described above (and illustrated in figure 1 and 2), the optimal q_1 is the permit sale which satisfies;

$$p_1 + \frac{\partial p_1}{\partial q_1} \cdot q_1 - \delta \cdot \left(p_2 + \frac{\partial p_2}{\partial q_2} \cdot q_2 \right) + \left(\frac{\partial C_{1M}}{\partial e_{1M}^*} - \delta \cdot \frac{\partial C_{2M}}{\partial e_{2M}^*} \right) \cdot \frac{\partial e_{1M}^*}{\partial q_1} = 0 \qquad (32)$$

Hence, if the first order condition (31) is satisfied for a q_1 that makes the non-borrowing constraint binding for the fringe, it is optimal for the monopolist to distribute the given total sale of permits such that the marginal revenue from permit sale in period one is equal to the marginal revenue from permit sale in period 2 minus the shadow cost of the non-borrowing constraint for the monopolist.

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[8] This assumption is satisfied if the marginal abatement cost functions for the fringe are linear or concave ($\frac{\partial^2 p_i}{(\partial q_i)^2} \le 0$). This will also be the case for convex marginal abatement cost functions ($\frac{\partial^2 p_i}{(\partial q_i)^2} > 0$) within a certain range where $2 \cdot (\frac{\partial p_1}{\partial q_1} + \frac{\partial p_2}{\partial q_2}) + \frac{\partial^2 p_1}{(\partial q_1)^2} \cdot q_1 + \frac{\partial^2 p_2}{(\partial q_2)^2} \cdot q_2 < 0$.

[9] It follows from our assumption about the marginal abatement costs that the difference in marginal abatement costs increases in q_1, for $-\frac{\partial C_{1M}}{\partial e_{1M}^*} > (-\delta \cdot \frac{\partial C_{2M}}{\partial e_{2M}^*})$.

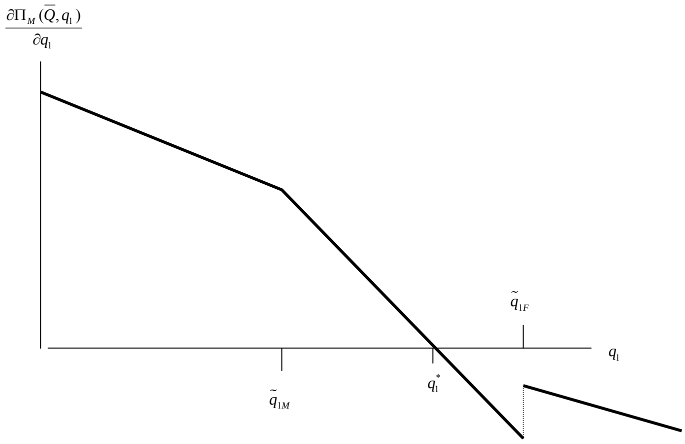

Figure 1.

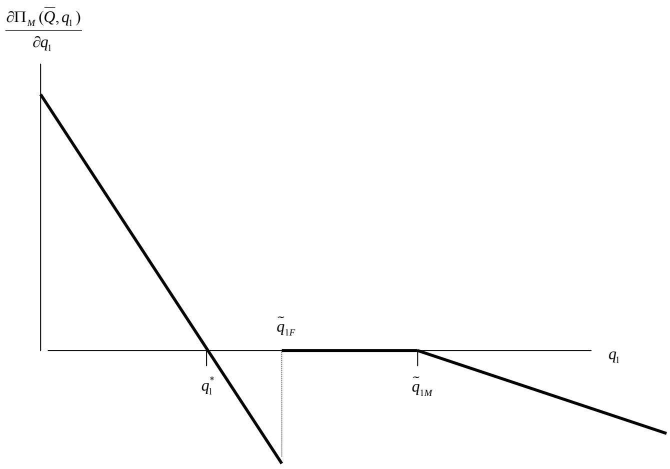

Figure 2.

2. For a marginal profit function described in situation iii) (illustrated in figure 3.), there is a range for optimal permit sales in period 1 which is characterized by
   $\tilde{q}_{1F} < q_1^* \leq \tilde{q}_{1M}$.
   Hence, if the first order condition (31) is satisfied only for a distribution of permit sale where the non-borrowing constraint does not bind for any of the agents, we cannot specify a specific optimal q_1, but we find an optimal range for q_1 which gives the monopolist identical profits.

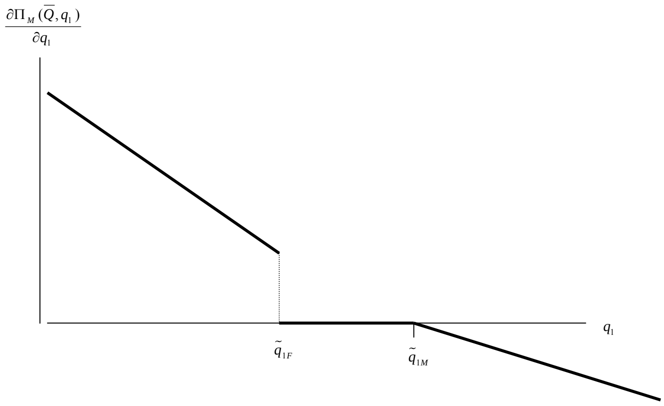

Figure 3.

3. For profit functions described in situation iv) (illustrated in figure 4.), $\frac{\partial \Pi_M(\overline{Q}, q_1)}{\partial q_1} > 0 \quad for\ q_1 \le \tilde{q}_{1F}, and\ \frac{\partial \Pi_M(\overline{Q}, q_1)}{\partial q_1} < 0\ for\ q_1 > \tilde{q}_{1F}$. The profit maximizing solution is then given by $q_1^* = \tilde{q}_{1F}$.
Hence, if there is no q_1 that satisfies (31), we have a corner solution. In this case we find a unique optimal permit sale in period 1, q_1^*, where the monopolist faces a binding non-borrowing constraint and sell exactly so many permits that the fringe's marginal abatement costs are equalized across periods; i.e. $p_1(q_1) = \delta p_2(q_2)$.

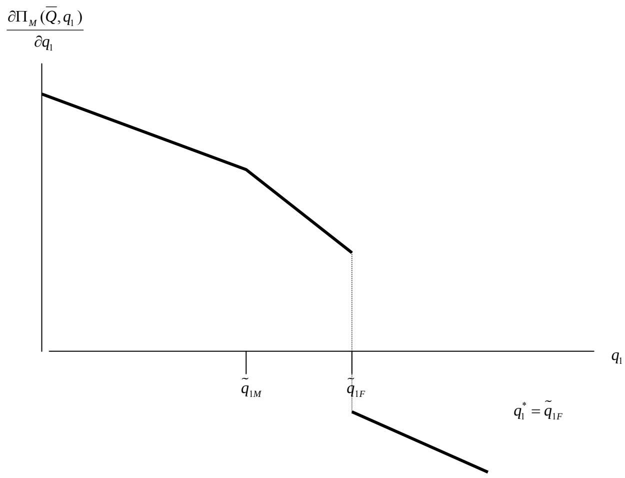

Figure 4.

By the definitions of $\tilde{q}_{1F}$ and $\tilde{q}_{1M}$ we see that that if $\tilde{q}_{1M} > \tilde{q}_{1F}$, there is a range for the first period permit sales, defined by $\tilde{q}_{1M} - \tilde{q}_{1F}$, which makes the non-borrowing constraint non-binding for all agents. However, if $\tilde{q}_{1M} < \tilde{q}_{1F}$, a first period permit sale that leads to a non-binding constraint on borrowing for the fringe cannot be achieved without a binding constraint on borrowing for the monopolist. Hence, the lower the target for the first period emissions relative to the total target for emissions, the more likely is it that the monopolist faces a restriction on its possibility to manipulate with the price difference between periods via its own non-binding constraint on borrowing; i.e. $\tilde{q}_{1M} < \tilde{q}_{1F}$.

The monopolist's exploitation of a non-borrowing constraint to increase its profit can be seen most explicitly in the case where $\tilde{q}_{1M} > \tilde{q}_{1F}$. In this situation, a cost-effective distribution of permit sales across periods would imply that the shadow cost of the non-borrowing constraint would be zero for all agents, i.e. that the present value of the marginal abatement costs are equal across periods.[10] However, we see from figure 2 that the monopolist may choose a distribution of sale which does not yield the cost-effective outcome for the distribution of permit sales across periods.

If we have an interior solution given by (32), and the non-borrowing constraint is not binding for the monopolist, that is $\lambda_M = 0$, we can rewrite the first-order conditions in terms of elastisities and get

$$p_1\left[1-\frac{1}{|\varepsilon_1|}\right] = \delta \cdot p_2\left[1-\frac{1}{|\varepsilon_2|}\right] \qquad (33)$$

where

$$\varepsilon_i = \frac{p_i}{q_i}\cdot\frac{\partial q_i}{\partial p_i} \quad i = 1,2$$

is the elasticity of demand facing the monopolist in period *i*, evaluated at the profit-maximizing choices of permit sale.

The equilibrium condition given by (33) is the well known result from the theory of third-degree price discrimination: the market with the higher price must have the lower elasticity of demand; the market that is more price sensitive is charged the lower (present value) price. (See for instance Varian (2003)).

There are two differences between the standard third-degree price discrimination problem and the problem in our study. First, due to the non-borrowing constraint in our problem, the present value price of permits cannot increase over time. Hence, in the case where $\lambda_M = 0$, the monopolist can only take advantage of the non-borrowing constraint facing the fringe if the elasticity of demand increases over time. Second, in the literature on third-degree price discrimination, the cost of producing the good is generally assumed to be independent of which market being served. In our case, the non-borrowing constraint may become binding also for the monopolist, hence making it more costly to produce the good (sell permits) in period 1 than in period 2. The monopolist in our case must therefore also take into account the

[10] See eqs. (9) and (10). λ_2 from eq. (10) would equal zero.

effect on its own production cost (abatement cost) when it finds the optimal distribution of sale over time.[11]

From the discussion of the first order condition above, we can derive the following proposition:

Proposition 1:

If the non-borrowing constraint is binding for any of the agents in equilibrium, there is a cost-ineffective distribution of sales over time (except by coincidence). If the non-borrowing constraint is *not* binding for any of the agents, there is a cost-effective distribution of sales across periods.

Proof:

If the optimal solution is characterized by (32) (, the non-borrowing constraint is binding for one or both of the agents see figure 1 and 2). Recall that. $(-\frac{\partial C_{1F}}{\partial e_{1F}^*} - (-\delta \frac{\partial C_{2F}}{\partial e_{2F}^*})) = p_1 - \delta p_2$.

The intertemporal efficiency condition given by (9) is hence satisfied only if (by coincidence)

$$\frac{\partial p_1}{\partial q_1^*} \cdot q_1^* = \delta \frac{\partial p_2}{\partial q_2^*} \cdot q_2^* \quad where\ q_2^* = \overline{Q}_M - q_1^* . \tag{34}$$

If the optimal solution is characterized by the third solution described above, (i.e.) $q_1^* = \tilde{q}_{1F} > \tilde{q}_{1M}$ (see figure 4), the non-borrowing constraint is binding for the monopolist, but not for the fringe. In this case, $p_1 = \delta p_2$, and hence, $(-\frac{\partial C_{1F}}{\partial e_{1F}^*} - (-\delta \frac{\partial C_{2F}}{\partial e_{2F}^*})) = 0$, whereas $-\frac{\partial C_{1M}}{\partial e_{1M}^*} - (-\delta \cdot \frac{\partial C_{2M}}{\partial e_{2M}^*}) > 0$ for q_1^*. Equation (9) is not satisfied.

If the optimal solution is characterized by $\tilde{q}_{1F} < q_1^* \le \tilde{q}_{1M}$ (see figure 3), the non- borrowing constraint is not binding for any of the agents ($\lambda_F = \lambda_M = 0$), and we see from (13)-(15) and (27) that the intertemporal cost-effectiveness condition (9) is satisfied.

□

Proposition 1 tells us that introducing a non-borrowing constraint allows the monopolist to manipulate the price difference over time. And this may lead to an inefficient distribution of sales and hence emissions over time.

Since we have a one-way separation of the market, the monopolist will not always be able to take advantage of the opportunity for manipulating the price difference over time. Consider

[11]The monopolist's optimizing problem in our study resembles the monopolist's optimizing problem in the literature on monopoly and the rate of extraction of exhaustible resources. For the extraction of an exhaustible resource, the marginal cost of production may differ over time. Lewis (1976) and Stiglitz (1976) examine conditions for when the price path for a natural resource, produced by a monopoly, deviates from the optimal (competitive) price paths, and in which direction it deviates. However, in their analysis it is assumed that buyers do not have the possibilities to either bank or borrow. Hence, the monopolist is not restricted from letting the present value price increase over time.

the case where the monopolist receives a sufficiently high amount of initial permits in period 1 such that the non-borrowing constraint is not binding for the monopolist for a distribution of permit sale which gives $p_1 = \delta p_2$. If the demand for permits is more price sensitive in period 1 than in period 2, that is if $|\varepsilon_1| > |\varepsilon_2|$ for $p_1 = \delta p_2$, the monopolist would have preferred to sell more permits in period 1 and less permits in period 2 which would result in $p_1 < \delta p_2$. However, because the fringe can bank permits, and thus the possibility for arbitrage, this could not be an equilibrium, and the monopolist is forced to not let the price in period 1 be lower than the present value price in period 2. So in this case, the monopolist could not take advantage of the non-borrowing constraint faced by the fringe (see figure 3).

Proposition 2. A constant present-value price over time does not imply a cost- effective distribution of abatement (permit sales) across periods.

Proof: It follows directly from the second part of the proof for proposition 1.

□

One might think that a constant present-value price over time is consistent with a cost-effective distribution of sales across periods, and hence that a non-borrowing constraint does not influence the outcome in this case. However, we may observe identical present-value prices of permits over time, although a cost-effective distribution of abatement across periods would be consistent with a positive shadow cost of the non-borrowing constraint, and hence a decrease in the present-value price of permits over time. This implies that although the costs of the fringe are minimized when the present-value price of permits is constant over time, the monopolist would manipulate the distribution of emissions across periods by selling more of the permits in period 1 to increase its profit. This is the case when the marginal revenue of permit sales is higher in period 1 than in period 2 for a cost-effective distribution of sales across periods (i.e where $p_1 > \delta p_2$). As long as the increase in income from permit sales gained by transferring sales from period 2 to period 1 is higher than the increase in the monopolist's total abatement cost by such a transfer, the monopolist will benefit from the transfer of sale. For $q_1 > \tilde{q}_{1F}$, the monopolist cannot increase its income from permit sales by additional transfer of permit sales from period 2 to period 1, since $p_1 = \delta p_2$ for $q_1 > \tilde{q}_{1F}$, and the solution to the profit maximizing problem for the monopolist is $\tilde{q}_{1F} < q_1^* \le \tilde{q}_{1M}$ (described in figure 3). Compared to a cost-effective distribution of abatement across periods, the monopolist's market power in the permit market has led to a situation where the difference in the present value of the marginal abatement cost over time has increased for the monopolist and decreased for the fringe such that eq. (9) is not satisfied.

3 The impact of initial distribution of permits over time

As we established in proposition 1, the intertemporal cost effectiveness condition (9) is generally not satisfied when the non-borrowing constraint is binding for any of the agents in equilibrium. In the following section we analyze how the initial distribution of permits across periods affects the intertemporal cost effectiveness, and whether it is possible, through a proper intertemporal distribution of permits, to achieve intertemporal cost effectiveness, i.e. fulfill equation (9). We consider a redistribution of permits across agents and across time, which leaves the target for total emissions in each period and the total endowments of permits over both periods for each agent unchanged. This implies that the first period emission constraint, given by (7), and the total emission constraint, given by (6) are unchanged.

Let the total initial allocation of permits to each of the agents over both periods be a constant, denoted Q_j^0, j = F,M , and the total allocation of permits for each period is a constant, denoted Q_i^0, i =1,2. Then we must have $Q_j^0 = Q_{1j}^0 + Q_{2j}^0$ and $Q_i^0 = Q_{iF}^0 + Q_{iM}^0$. We can write the initial allocation of permits for each agent in each period as a function of the initial allocation of permits to the monopolist in period 1, that is $Q_{ij}^0(Q_{1M}^0)$. We first consider the impact of the distribution of permits across periods when we have an interior solution.

Proposition 3. The total cost of the agreement can be reduced by giving the monopolist a lower share of the first period permits if $(-\frac{\partial C_{1F}}{\partial e_{1F}^*} - (-\delta\frac{\partial C_{2F}}{\partial e_{2F}^*})) > (-\frac{\partial C_{1M}}{\partial e_{1M}^*} - (-\delta\frac{\partial C_{2M}}{\partial e_{2M}^*}))$ **in equilibrium, and a higher share of the first period permits if** $(-\frac{\partial C_{1F}}{\partial e_{1F}^*} - (-\delta\frac{\partial C_{2F}}{\partial e_{2F}^*})) < (-\frac{\partial C_{1M}}{\partial e_{1M}^*} - (-\delta\frac{\partial C_{2M}}{\partial e_{2M}^*}))$**, (given that the optimal solution is an interior solution).**

Proof: Since $Q_{1F}^0 + Q_{1M}^0 = Q_1^0$ and $Q_{1j}^0 + Q_{2j}^0 = Q_j^0 \quad (j = F, M)$, and Q_1^0 and Q_j^0 are constants, we find that $\frac{\partial e_{1j}^*}{\partial Q_{1M}^0} = -\frac{\partial e_{2j}^*}{\partial Q_{1M}^0}$ and $\frac{\partial e_{1F}^*}{\partial Q_{1M}^0} = -\frac{\partial e_{1M}^*}{\partial Q_{1M}^0} = 1$ when the non-borrowing constraints are binding. We find that

$$\frac{\partial TC}{\partial Q_{1M}^0} = \left[\left(-\frac{\partial C_{1M}}{\partial e_{1M}^*} - (-\delta\frac{\partial C_{2M}}{\partial e_{2M}^*})\right) - \left(-\frac{\partial C_{1F}}{\partial e_{1F}^*} - (-\delta\frac{\partial C_{2F}}{\partial e_{2F}^*})\right)\right] \cdot \left[\frac{\partial q_1^*}{\partial Q_{1M}^0} - 1\right]$$

where q_1^* is the solution to (32) and $-\frac{\partial C_{1j}}{\partial e_{1j}^*} - (-\delta\frac{\partial C_{2j}}{\partial e_{2j}^*}) = 0 \quad for\ \lambda_j = 0$

We find from total differentiation of (32) that $\frac{\partial q_1^*}{\partial Q_{1M}^0} = \frac{-A + \frac{\partial p_1}{\partial q_1^*} - \frac{\partial p_2}{\partial q_2^*}\cdot\frac{\partial q_2^*}{\partial q_1^*}}{-A}$,

where A is the expression for the second-order condition for profit maximization and will be negative if the second-order sufficiency condition for maximum obtains. [12]

It follows from (22) and (23) and the fact that $\frac{\partial q_2^*}{\partial q_1^*}$ = -1, that $\frac{\partial q_1^*}{\partial Q_{1M}^0} < 1$.

□

If the difference in the present value of marginal abatement cost over time is higher for the fringe than the monopolist, a redistribution of the endowment of permits which leads to

[12] It follows from our assumption that the marginal revenue is decreasing in q_1 for all $q_1 \le \tilde{q}_{1F}$, that the second-order sufficiency condition is satisfied (see footnote 8).

higher emission from the fringe and lower (or equal) emission from the monopolist in period 1, and vice versa in period 2, would reduce the cost of the agreement. As an example, consider the case where $-\frac{\partial C_{1M}}{\partial e^*_{1M}} - (-\delta \frac{\partial C_{2M}}{\partial e^*_{2M}}) = 0$ and $-\frac{\partial C_{1F}}{\partial e^*_{1F}} - (-\delta \frac{\partial C_{2F}}{\partial e^*_{2F}}) > 0$ (this corresponds to the solution illustrated in figure 4).[13] Thus, in this example the non-borrowing constraint is binding for the fringe, but not for the monopolist. Transferring permits from period 1 to period 2 for the monopolist, and vice versa for the fringe, would not influence the difference in marginal abatement costs across periods for the monopolist since the monopolist faces a non-binding non-borrowing constraint. However, this would reduce the difference in marginal abatement costs across periods for the fringe and hence reduce the fringe's total abatement cost. This reduction in cost will be somewhat offset by a reduction in the monopolist's optimal number of permit sold. But since we find that the reduction in permit sales, following from a decrease in allocation of initial permits in period 1, is less than 1, ($\frac{\partial q^*_1}{\partial Q^0_{1M}} < 1$), the net effect is a reduction in the fringe's total abatement costs. On the other hand, if $-\frac{\partial C_{1M}}{\partial e^*_{1M}} - (-\delta \frac{\partial C_{2M}}{\partial e^*_{2M}}) > 0$, the opposite would be the case.

Proposition 4. As long as the solution to the monopolist's optimization problem is the corner solution (characterized by the solution no. 3. in section 2.2.2), a marginal redistribution of first-period emission permits between the agents has no effect on the total cost.

Proof:

Let q^*_1 be the solution which ensures $p_1 = \delta p_2$. We find that (see proof for proposition 4.):

$$\frac{\partial TC}{\partial Q^0_{1M}} = \left[\left(-\frac{\partial C_{1M}}{\partial e^*_{1M}} - (-\delta \frac{\partial C_{2M}}{\partial e^*_{2M}})\right) - \left(-\frac{\partial C_{1F}}{\partial e^*_{1F}} - (-\delta \frac{\partial C_{2F}}{\partial e^*_{2F}})\right)\right] \cdot \left[\frac{\partial q^*_1}{\partial Q^0_{1M}} - 1\right]$$

As long as the abatement cost function of the fringe and the monopolist is such that it is optimal for the monopolist to let $p_1 = \delta p_2$, although this implies that $\left(-\frac{\partial C_{1M}}{\partial e^*_{1M}} - (-\delta \frac{\partial C_{2M}}{\partial e^*_{2M}})\right) > 0$ >0, we find the expression for $\frac{\partial q^*_1}{\partial Q^0_{1M}}$ by differentiation of the optimal condition $p_1 = \delta p_2$. From (22) and (23) we see that

$$\frac{\partial q^*_1}{\partial Q^0_{1M}} = \frac{\frac{\partial^2 C_{1F}}{(\partial e^*_{1F})^2} + \frac{\partial^2 C_{2F}}{(\partial e^*_{2F})^2}}{\frac{\partial^2 C_{1F}}{(\partial e^*_{1F})^2} + \frac{\partial^2 C_{2F}}{(\partial e^*_{2F})^2}} = 1$$. This means that $\frac{\partial TC}{\partial Q^0_{1M}} = 0$.

□

[13] Note that changes in Q^0_{1M} would both affect the marginal profit function and the level of $\tilde{q}_{1F}$ and $\tilde{q}_{1M}$.

Giving a higher share of the first-period permits to the monopolist only leads to a corresponding higher sale of permits. And the distribution of emissions across agents and periods would be the same.

However, the redistribution of permits leads to a lower marginal profit from permit sales, which implies that for a sufficiently high redistribution of permits, the solution to the monopolist's profit maximizing problem could change from a corner solution to an interior solution (given by (32)). This leads to the following proposition:

Proposition 5. A cost-effective distribution of abatement across periods can be achieved by an appropriate distribution of first-period emission permits between the agents.

Proof: If the monopolist has chosen to distribute permit sale such that (32) (interior solution) is satisfied, we see from the proof of proposition 2 that total cost can be reduced by changes in Q_{1M}^0 , as long as $(-\frac{\partial C_{1F}}{\partial e_{1F}^*} - (-\delta \frac{\partial C_{2F}}{\partial e_{2F}^*})) \neq (-\frac{\partial C_{1M}}{\partial e_{1M}^*} - (-\delta \frac{\partial C_{2M}}{\partial e_{2M}^*}))$. We see from the first-order condition (32), that intertemporal cost efficiency is achieved for the distribution of initial permits, which ensures that $\frac{\partial p_1}{\partial q_1^*} \cdot q_1^* = \delta \frac{\partial p_2}{\partial q_2^*} \cdot q_2^* \quad where\ q_2^* = \overline{Q}_M - q_1^*$.

If the monopolist's optimization problem leads to a corner solution, we still find that

$$\begin{aligned}\frac{\partial^2 \Pi_M (\overline{Q}, q_1^*(Q_{1M}^0)}{\partial q_1^* \partial Q_{1M}^0} &= \frac{\partial^2 \Pi_M (\overline{Q}, q_1^*)}{\partial q_1^* \partial Q_{1M}^0} + \frac{\partial^2 \Pi_M (\overline{Q}, q_1^*)}{\partial q_1^* \partial q_1^*} \cdot \frac{\partial q_1^*}{\partial Q_{1M}^0} \\ &= \frac{\partial p_1}{\partial q_1^*} + \delta \cdot \frac{\partial p_2}{\partial q_2^*} < 0\end{aligned}$$

This means that the marginal income from selling the last unit of permits is lower, the higher Q_{1M}^0 . A sufficiently large Q_{1M}^0 , and hence low Q_{1F}^0 , will make the marginal profit from selling the last unit of permits in the corner solution equal to zero. An additional increase in Q_{1M}^0 from that point will make it optimal for the monopolist to choose an interior solution. Hence, a sufficiently large transfer of initial first-period permits from the fringe to the monopolist would move the optimal solution for permit sales from a corner solution (as in figure 4) to an interior solution (as in figure 1.), where a cost-effective distribution of abatement across periods is achieved for a distribution of permits to the monopolist that ensures that (34) is satisfied.

□

4 The impact of changes in market structure over time

In the previous section we discussed how the initial distribution of permits across agents influences cost-effectiveness when one of the agents has market power. We assumed that one of the agents (the monopolist) is a larger seller of the total number of permits sold on the market. However, the structure of the permit trading system may change over time and include more emitters in future periods than in the first period.[14] We may face a situation where we initially have few emitters included in the permit trading system, while inclusion of more emitters over time expands the market for emission trading in the future. The monopolist in our model may hence face a situation where it has a lot of permits to sell in the first period, but this amount is relatively low compared to the expected total sale of permits in the second period. The question we ask is how the restrictions on intertemporal trading influence the dominant agent's opportunity to exploit its market power when there is a change in market structure over time.

From the analyses in the previous sections, we derive the following proposition:

Proposition 6: Assume a dominant agent in the first period and a competitive market in the second period. If there are no restrictions on banking or borrowing, this will undermine the ability of the first-period dominant agent to exploit its market power.

If the agents have perfect foresight, the dominant agent cannot charge a higher (present value) price in period 1 than the competitive second period price. If the agent with a dominant position in the first period is too small to have a dominant position in the total market for permits over both periods, the agent cannot influence the price of permits. The competitive outcome is realized, and marginal abatement costs are equalized across agents and across periods, which implies cost-effectiveness.

However, the introduction of a restriction on borrowing gives a dominant agent in the first period the opportunity to take advantage of its dominant position in the first period.

Proposition 7: If there is a restriction on borrowing, a dominant agent in the first period and a competitive market in the second period, then the monopolist will exploit its market power in the first period as long as $q_1 > 0$. The price in the first period would exceed the competitive price in the second period.

Proof:

In a competitive second period market, the monopolist cannot influence the second period price, that is $\frac{\partial p_2}{\partial q_2} = 0$. We first show that $p_1 = \delta \cdot p_2$ is not a possible equilibrium.

The marginal profit of selling q_1 when the monopolist minimizes its abatement cost and $\frac{\partial p_2}{\partial q_2} = 0$ is given by

$$\frac{\partial \Pi_M(\overline{Q}, q_1)}{\partial q_1} = \left[p_1 + \frac{\partial p_1}{\partial q_1} \cdot q_1 - \delta \cdot p_2 \right] + \frac{\partial C_{1M}}{\partial e_{1M}} - \delta \cdot \frac{\partial C_{2M}}{\partial e_{2M}}. \tag{35}$$

[14] For instance in the case of the Kyoto Protocol, the dominant agent's (Russia's) position in the permit market might change in the future if, for instance, developing countries participate in the permit trading system. Also, within other permit trading systems, choosing to include more industries in trading of emission permits might make the market more competitive.

We see from the description of the possible solutions 1 - 3 in section 2.2.2 that $p_1 = \delta \cdot p_2$ in equilibrium implies that eq. (35) must be non-negative for $p_1 = \delta \cdot p_2$. (Positive for the corner solution characterized by 3, and zero for the solutions characterized by 1 and 2 in section 2.2.2). However if eq. (35) is non-negative for $p_1 = \delta \cdot p_2$, we must have that $-\frac{\partial C_{1M}}{\partial e_{1M}^*} - (-\delta \cdot \frac{\partial C_{2M}}{\partial e_{2M}^*}) < 0$, since $\frac{\partial p_1}{\partial q_1} \cdot q_1 < 0$, which contradicts (27)and (28) . This means $p_1 > \delta \cdot p_2$ and we can rule out the optimal solutions characterizes by 2 and 3 as possible equilibriums. The solution to the monopolist optimizing problem is given by (32). The optimal condition (32), when $\frac{\partial p_2}{\partial q_2} = 0$ is given by

$$-\frac{\partial C_{1M}}{\partial e_{1M}} - (-\delta \cdot \frac{\partial C_{2M}}{\partial e_{2M}}) - \left[p_1 + \frac{\partial p_1}{\partial q_1} \cdot q_1 - \delta \cdot p_2 \right] = 0$$

It follows from the fact that $-\frac{\partial C_{1M}}{\partial e_{1M}^*} - (-\delta \cdot \frac{\partial C_{2M}}{\partial e_{2M}^*}) \geq 0$ and $\frac{\partial p_1}{\partial q_1} \cdot q_1 < 0$, that the intertemporal cost effectiveness condition (Equation (9)) never will be satisfied for $q_1 > 0$.

□

When the monopolist faces a competitive market in future periods, the income from each permit sold in period 2 will not decline in quantity sold. Hence transferring permit sales from period 1 to period 2 does not reduce the income per unit sold in period 2. (This is opposed to the situation where the monopolist had market power in both markets. In that case, increased permit sales in period 2 led to a lower price in period 2.) Restricting permit sales in period 1 in order to increase the permit price has hence no alternative cost in terms of a reduction in prices in period 2. Hence it will always be optimal for a monopolist to restrict sales in period 1 and increase sales correspondingly in period 2, such that the $p_1 > \delta \cdot p_2$.

Hence, with a dominant agent in the first period and a competitive permit market in the second, restricting intertemporal trading to banking results in a dominant agent in period 1 getting the opportunity to exploit its market power. This is opposed to the situation with full intertemporal trading where the market power of the dominant agent would always be undermined.

5 Total cost effects

So far we have only considered the intertemporal inefficiency of prohibiting borrowing when the monopolist's total sale of permits ($\overline{Q_1}$) is given, when there is a non–borrowing constraint. To obtain the effects on total costs of prohibiting borrowing we also have to consider how total permit sale is affected as result of the possibility for the monopolist's possibility to price discriminate between periods.

The effect on total cost of introducing a non-borrowing constraint can be divided in three.

First, introducing a non-borrowing constraint may have a negative impact on the total cost of reaching a specific target for *total* emissions over both periods, even if there is no agent exerting market power. This is the case if the shadow cost of the non-borrowing constraint becomes positive (see eq.(10)). Second, as we have derived in section 2.2.2, the monopolist can take advantage of the possibility of manipulating the price difference between periods such that intertemporal cost effectiveness, given the non-borrowing constraint, is not satisfied. (Equation (9) is not satisfied). As we have seen in section 3, this manipulation increases the total cost of reaching the target. Third, the opportunity for manipulating the price difference across periods may also result in another optimal total sale over both periods compared to the optimal solution under full intertemporal trading.

Since the focus of this paper is on how a dominant firm takes advantage of a non-borrowing constraint, we ignore in the following the first effect by considering a situation where the monopolist can choose to what extent total permit sales could be distributed across periods such that the shadow cost of the non-borrowing constraint would be zero for all agents. Hence, we consider a situation described in figure 2 for all possible choices of $\overline{Q}$. As discussed above, the monopolist can manipulate the price difference over time and cause an intertemporal inefficiency, but this possibility of manipulation may also lead to higher or lower total permit sales, $\overline{Q}$. Hence, the increase in total cost of introducing this non-borrowing constraint not only depends on the impact of how the monopolist distributes permit sales across periods, but also on the impact on the total sale of permits. Obviously, if the monopolist's ability to charge different prices over time also makes it optimal for the monopolist to increase its total sale of permits, the increased sales could offset the inefficiency from a non-optimal distribution of emissions across periods. If total sales do not increase, the implication of introducing a non-borrowing constraint is that the total cost of the agreement increases, whenever the shadow cost of the non-borrowing constraint differs across agents.[15] Whether the opportunity to price discriminate leads to a greater or lesser sale of permits depends on the curvature of the demand functions for permits over time. This is formally analyzed in Schmalensee (1981) and in Varian (1985). Schmalensee (op.cit.) shows that the total output would decline (increase) under price discrimination compared to a situation without price discrimination with specific conditions for the demand curves. A declining (increasing) total output would be the case if all the markets with price discrimination that have prices higher than the price without price discrimination (p*) have concave (convex) demand curves, while all markets with prices less than p* have linear demand curves. If all demand curves are either convex or concave we cannot in general say whether output will raise or fall. Further, Robinson (1933) shows that if a monopolist that sells in two markets is allowed to discriminate between them, total output is unchanged if both markets have linear demand curves.

In our case, this implies that we obtain a clear result for the effect on total costs of prohibiting borrowing when this leads to an ineffective distribution of permits across periods and when total permit sales decrease because of price discrimination between periods. Hence:

Proposition 8: If we observe $p_1 > \delta p_2$, introducing a non-borrowing constraint (which is not binding with a cost-effective distribution of permit sales across periods), will increase total costs if:

- **the demand for permits in period 1 is concave, while the demand for permits in period 2 is linear, or**
- **the demand for permits in both periods is linear.**

[15] Schmalensee (1981) shows that an increase in output is a necessary condition for welfare to increase under third-degree price discriminations.

However, if this is not the case, the effects on total costs of prohibiting borrowing would be unclear, when we observe $p_1 > \delta p_2$.

Obviously, total cost would be unchanged if the monopolist finds it optimal to let $p_1 = \delta p_2$ (if the constraint on borrowing is non-binding with a cost-effective distribution of permits across periods).

6 Discussion

Several studies have underlined the opportunities for exercising of market power in the permit market. Hahn (1984) is the first to explore this issue, but a lot of others have followed, such as Westskog (1996), Bernstein et al (1999) and Böhringer (2002). All of this literature analyzes the consequences of agents exercising market power in one period, and does not take into account how future permit-market developments influence the ability of a dominant agent to explore its market power. Further, none of these studies analyzes the consequences for the permit price of having a binding restriction on borrowing. Our study shows that their conclusions regarding the permit price for instance under the Kyoto Protocol need to be reexamined. We have shown that even if a restriction on borrowing would not have efficiency consequences in a competitive market of permits, i.e. be non-binding for the agents, a dominant agent might take advantage of this restriction to increase its market power, and we may face a higher permit price in the first period than otherwise expected. Further, we have shown that a constant present-value price of permits could still imply that the monopolist had taken advantage of the non-borrowing constraint, i.e. that a constant present value price of permits does not necessarily imply a cost-effective distribution of abatement across periods.

However, we have also pointed out that the regulator can influence total abatement costs through distribution of permits over time even under a constraint on equity. A cost-effective distribution of abatement across periods could be obtained by an appropriate distribution of each agent's total endowment of permits over time. Hence, the regulator could take equity considerations into account at the same time as achieving a cost-effective outcome.

Finally, we have shown that the market structure in the future might influence the ability of a dominant agent to explore its market power. If we face a competitive permit market in future periods, but have a dominant agent in the first period without a binding restriction on borrowing, the ability of a dominant agent to explore its market power might be undermined in that period, and the permit price might be lower than otherwise expected.

A relevant example of the problem addressed here would be the allocation of permits to Russia under the Kyoto Protocol. Here, Russia has been allocated a very large amount of permits in the first period, and only banking of emission permits is allowed under the Protocol. Russia might take advantage of this to increase its market power by selling so few permits that the restriction on borrowing becomes binding for the purchasing agents. This would be possible even if a competitive market is expected in the next commitment period, and the permit price would be higher than otherwise expected.

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