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Distributional constraints and efficiency in a tradable permit market [1,2]

by

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Abstract

It is a well known result that taking distributional constraints into account when allocating tradable permits to different agents can lead to an imperfectly competitive permit market. Hence, the emission target is no longer met at least cost. In this paper we suggest an allocation rule for permits which can handle this problem. If the permits are allocated twice during the same period, and the allocation in the second round is dependent on the market price for permits, this allocation rule can achieve both cost effectiveness and meet specific requirements for cost distribution across agents.

Categories: Climate Change, Emission Permits, Allocation, Cost Effectiveness, Distributional Constraints

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Distributional constraints and efficiency in a tradable permit market

1 Introduction

How costs of reducing emissions are divided between agents within an emission trading system is often a fundamental question when permits are allocated to the agents.[4] This concern stems not only from equity considerations, but also from the perspective of possibly using permit allocation as a mechanism to achieve participation from different agents. Lump sum transfers could in principle take care of the equity concerns and requirements for getting agents to participate. Within international permit trading systems, however, money transfers may not be acceptable means of cost distribution. For instance, in the Kyoto Protocol, the only policy instrument for distributing costs between participants is the allocation of permits across countries.[5] At the national level as well, trade rules can restrict the possibilities for financial transfers/tax reductions, and permit allocations may be the only mechanism available for dividing costs of reducing emissions between agents. Hence, there is often only one available mechanism for distribution costs between agents, namely the allocation of permits between them.

[4] The way that the EU target (a total of 8% reduction for the EU countries) in the Kyoto Protocol was distributed between the EU countries shows that cost considerations are an important element in deciding how to allocate emission reduction targets between the EU-countries. The low-income countries in the EU region, such as Portugal and Greece, were given much lower targets for reductions (in fact they could increase their emissions) than the other regions of the EU (See for instance European Environment Agency 2004).

[5] For instance, Russia obtained quite lax emission reduction requirements under the Kyoto Protocol, i.e. large allotments of free permits. This was probably necessary to achieve participation from Russia under the Protocol. In the future, allocating large allotments of free permits could also be an instrument for achieving participation from additional countries in a Kyoto-like agreement. Further, Ringius et al 2002 discuss the importance of fairness in international climate policy and argue that the differentiation of targets in the Kyoto Protocol evidences the need for fairness and justice in global climate policy. In the Kyoto Protocol, these fairness considerations are taken care of through the initial permit allocation between agents..

The way permits are allocated, or the size of the shares given to the different participants, can determine how cost-effective the system is. In a competitive permit market, the emissions target will be achieved at least cost regardless of how permits are allocated between agents. On the other hand, if the permits are allocated so that some agents become large traders of permits, the target will no longer be achieved at least cost.[6] Exploitation of market power leads to a sub-optimal distribution of abatement across agents and thus increases the total cost of achieving the target for emissions reduction.

Hahn (1984) shows that market power in the tradable permit market could lead to efficiency losses. The size of this loss depends on how the distribution of permits is made. As shown by Hahn (op.cit.) a cost-effective permit sale could be reached by distributing permits in such a way that the amount of permits given to a dominant agent equals the amount the dominant agent wants to have after permit trading has taken place . Further, as explained in Tirole (1988) an efficient subsidy of the monopolist's output causes the monopolist to produce the competitive output, and cost-effectiveness is hence achieved. When there is a monopsonist in the market, an efficient subsidy of the monopsonist's purchase would also lead to a competitive outcome. However, redistributing permits or using subsidies to achieve cost-effectiveness implies a redistribution of costs across agents. Restrictions on cost distribution due to requirements for participation or equity considerations could make it infeasible to subsidize/tax a dominant permit seller per unit sold/bought or allocate permits so as to reduce the efficiency loss from dominant agents exercising market power. Hence, the mechanisms suggested by Hahn (1984) and Tirole (1988) to reduce the efficiency loss from market power might not be feasible with restrictions on the distribution of costs between agents, and when the only available mechanism for achieving the desirable cost distribution is through the permit allocation between agents.

[6] The opportunity to exercise market power by some agents in a permit trading system is influenced by several factors, including how the permit system is designed (see Hagem and Westskog 1998 op.cit.), which agents are included in the system, and how many permits they receive (see Hahn 1984 op.cit or Westskog 1996.). For example, the amount of permits Russia received in the Kyoto Protocol for the first commitment period is likely to make Russia a large seller of permits (see Böhringer and Löschel 2003 and Weyant and Hill 1999).

Also, for a regulator[7] it is often not clear when the distribution of permits is made whether agents will exercise market power or not. For instance, consider an international permit trading system where one country gets a large share of permits. In this case, whether an agent would exploit its potential market power in the permit market will depend on its domestic climate policy. Allocating permits across several domestic agents and letting them trade in the international permit market will lead to a competitive market, whereas letting one agent take care of the international permit sale will probably lead to a situation where the agent could exploit its ability to keep a high permit price through a restriction on permit sale. When the allocation of permits to the agents is made, it is often not clear to the regulator how the national system will be designed or how the agents will behave under the system in general. In this situation, subsidizing permit sales will lead to cost ineffectiveness if the agents acted as price takers.

In this paper, we ask whether we could design a permit allocation rule that both meets the restrictions set on the cost distribution between the agents and leads to a cost-effective emission trading system when the only available mechanism for distribution of costs is the allocation of permits between the agents. In the following, we set up the model for the competitive outcome and relate this to the preferred distribution of cost for the regulator. Then we examine by the use of a simple one-period model with a dominant seller and a competitive fringe how a permit allocation rule could be designed to take into consideration both cost effectiveness and the restrictions on the distribution of the costs of reducing emissions. We suggest an allocation rule where permits are allocated twice to the agents during the same target period[8]; that is, a share of the total amount of endowments are held back by the regulator, and allocated after the permit price is observed in the market for permits. In the last part of the paper, we discuss how uncertainty regarding the agents' abatement cost functions would influence our results.

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[7] In this paper we use the term regulator in two senses. At the national level, this is the regulatory authority, while at the international level this would be the institutions that are set down within an international agreement to regulate the parties' behavior.

[8] By target period we mean, the period for which the agents' emission constraints are set.

2 The model

To illustrate our point, we start out with a simple model for a tradable permit system with only two types of agents. We consider a model where the emission targets for the different agents are set for one period. Further, the analyses below are conducted for the case where the regulator has a target for the distribution of cost across agents. We also assume that the regulator and both types of agent have perfect information about all agents' costs of reducing their own emissions.[9] There is one potential dominant agent in the permit market. We focus on a situation where compensation for participating in an emissions trading system must be paid to one agent through the allocation of permits between agents. When paying the compensation through the permit allocations, there is a risk that the compensation might lead to exercising of market power. In the following we assume that the dominant agent is a seller of permits, hereafter referred to as the monopolist, and denoted *M*. 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*. Overall, the fringe is a net buyer of permits.

The agents are allocated a total endowment of permits equal to Q_j, where *j* denotes the agent (*j=F,M*). The sum of the endowments allocated to the agents fulfills the total emissions constraint agreed upon; it is denoted Q and equals the sum of emissions from the agents:

$$Q = Q_F + Q_M = e_F + e_M \qquad (1)$$

where e_j signifies the emission of agent j.

Further, let $R_j(e_j)$ define the income of agent *j* of being able to emit e_j. We assume that $R_j(e_j)$ is twice continuously differentiable. The marginal income from emitting e_j ($R_j'(e_j)$) is positive and strictly decreasing; that is, $R_j'(e_j)>0$ and $R_j''(e_j)<0$. This signifies that as emissions reductions are carried out, income is reduced. The larger the

[9] This assumption is relaxed in section 8.

reductions in emissions, the higher the costs (loss in income) of additional emission reductions.

A cost effective distribution of emission across agent is found by maximizing the total income of emissions (denoted TR) subject to the emission constraint given by (1):

$$\underset{e_F, e_M}{Max}\, TR = R_F(e_F) + R_M(e_M) \tag{2}$$

subject to (1)

The first order condition of this maximization problem is given by:

$$R_M{}'(e_M) = R_F{}'(e_F) \tag{3}$$

which signifies that the marginal income from emissions must be equalized across agents to achieve a cost effective distribution of emissions.

The regulator's problem is now how to achieve the cost-effective distribution of emissions and at the same time fulfill the distributional constraint he/she has despite the existence of a dominant agent.

3 The competitive outcome and distribution of costs

In a competitive permit market, the agents will maximize their income from emissions minus the costs of buying permits (or plus the income of selling permits) subject to the emission constraint, which is given by:

$$Q_j + q_j = e_j \tag{4}$$

where q_j is the amount of permits bought ($-q_j$ is the amount of permits sold). Let p define the permit price. In a competitive permit market this price will be given for the different agents.

Hence, the agent's maximization problem is:

$$\underset{q_j, e_j}{\max} \Pi_j = R_j(e_j) - p \cdot q_j \tag{5}$$

Subject to (4)

The solution to this problem is:

$$p = R_j'(e_j) \tag{6}$$

which implies that each agent sets its emissions level where their marginal income from emissions is equal to the permit price, which results in a cost-effective outcome since marginal income is equalized across agents.

Let e_j^* be the solution to (6). Furthermore, let e_j^{BaU} denote agent *j*'s emissions in the absence of reductions (business-as-usual emissions). The agent *j*'s total cost of fulfilling its emissions reduction requirements is given by

$$TC_j = R_j(e_j^{BaU}) - R_j(e_j^*) + p \cdot (e_j^* - Q_j) \tag{7}$$

In a perfectly competitive market, the regulator's problem would be to find a distribution of the endowments of permits that achieves the regulator's preferred distribution of costs. Since we have assumed that the regulator has perfect information about all agents' income functions, it can derive the permit price in a competitive permit market. Hence, under a perfectly competitive permit market, we see from (7) that the regulator can achieve its preferred distribution of cost by an appropriate distribution of the endowments of permits $Q_{j,,}$ and this will ensure a cost-effective distribution of emissions across agents. Let $\overline{P}$ denote the competitive permit price and let TC_j^* denote the regulator's target for the distribution of cost between agents.

Furthermore, let Q_j^* denote the allocations of permits to agents that would ensure that the target for the distribution of costs between agents is achieved in a competitive permit market; that is, Q_j^* is the number of permits allocated free of charge which makes the right hand side of (7) equal to TC_j^*, for $p = \overline{P}$.

This preferred distribution of cost may give an agent a dominant position in the permit market. If a dominant agent exercises market power, the permit price will be higher than

$\overline{P}$, and costs will not be distributed as intended, nor will the system be cost effective. This is further discussed in section 4.

4 The Monopolist's optimization problem

The fringe will maximize the income from emissions minus the costs of buying permits which is equivalent to the maximization problem given by (5) subject to (4). The solution to this problem is given by (6) and the constraint (4). This defines the inverse demand function for permits given by:

$$p = p(e_F). \tag{8}$$

It follows from our assumptions about the income functions that the price the fringe is willing to pay for the permits is decreasing in its own emissions, i.e.:

$$\frac{\partial p}{\partial e_F} = R_F''(e_F) < 0.$$

If the dominant agent exploits its market power, it seeks to maximize its income from emissions plus the income from selling permits, given its emission constraints and the inverse demand function for permits given by (8).

$$\max_{e_M, q} \Pi_M(e_M) = R_M(e_M) + p(e_F)q \tag{9}$$

s.t. (1) and (4)

where q is the amount of permits sold to the fringe by the monopolist ($-q$ is the amount of permits bought by the fringe).

Inserting for q from the monopolist's emission constraint (4), and inserting for e_F from the total emission constraint (1), we can rewrite the monopolist's maximization problem to:

$$\max_{e_M} \Pi_M(e_M) = R_M(e_M) + p(Q - e_M) \cdot [Q_M - e_M] \tag{10}$$

The first order condition of this optimization problem is:[10]

[10] For a discussion of the second order condition, see section 6.

$$R'_M(e_M) - \frac{\partial p}{\partial e_F} \cdot q \; - p = 0 \qquad (11)$$

Let e_M^{NI} denote the solution to the monopolist's maximization problem under no intervention; that is, e_M^{NI} is the solution to (11). If the regulator does not intervene in the permit market, the dominant agent sells too few permits in order to drive up the permit price, and the distribution of emission across agent is not cost-effective ($R'_M(e_M^{NI}) < p \equiv R'_F(Q - e_M^{NI})$). In addition, the distribution of costs between agents would not be as intended; that is, TC_j^* would not be fulfilled. The question is whether it is possible for the regulator to intervene in the permit market such that both the target for cost-effectiveness and the distribution of costs across agent is achieved. In the following section we present an allocation rule for permits that ensures that both of these goals can be satisfied.

5 Adjustable allocation rule

We suggest an allocation rule where permits are allocated twice to the agents during the same target period; that is, a share of the total amount of endowments are held back by the regulator, and allocated after the permit price is observed in the market for permits. As shown in the following, this allocation rule makes it possible to distribute costs between the agents according to what is perceived as the desired distribution of costs and at the same time reach a cost-effective outcome.

At the beginning of the target period the agents are allocated a fixed amount of permits, denoted Q_j^1. The endowment of permits for the second round of allocations is dependent on the outcome of the permit price. If the price observed before the second round of permit allocations turns out to be the competitive permit price, the agent is given an amount of permits for the second round equal to Q_j^2. However if the price of permits are higher than the competitive price, the endowment is increased/reduced for the fringe/monopolist by a constant factor of β_j times the difference between the observed permit price and the competitive price $\overline{P}$. Hence, the allocation for the second round of allocations equals $Q_j^2 + \beta_j(p - \overline{P})$ where $\beta_M = -\beta_F$, and $\beta_F > 0$.

This means that we can write the allocation rule for each agent as:

$$Q_j = Q_j^1 + Q_j^2 + \beta_j(p - \overline{P}) \qquad \text{(j=F,M)}, \tag{12}$$

Hence, when the permit price exceeds the competitive price, $\overline{P}$, the second round of permit allocations benefits the fringe and punishes the monopolist through a reduction in the endowments of permits for the monopolist.

Let $\beta_F \equiv \beta$. The total emission constraints for the fringe and monopolist are given by, respectively,

$$e_F = Q_F^1 + Q_F^2 + \beta(p - \overline{P}) + q \tag{13}$$

$$e_M = Q_M^1 + Q_M^2 - \beta(p - \overline{P}) - q \tag{14}$$

The allocation rule is known to all agents at the beginning of the target period. Since all agents know each others costs of emission reductions, they can hence derive the competitive permit price and all agents can also deduct the second round allocation of permits when they observe the permit price. This imply that the monopolist will not be able to manipulate the permit sale to ensure a low permit price before the second round of allocations and a high permit price after this last round of allocations. Consequently, there can only be one equilibrium price in the market due to the possibilities for arbitrage if the price changes over time. Hence, the price observed before the second round of allocation will be the equilibrium price for the whole target period.

The regulator's problem is now to find a β that maximizes the total income of all agents under the restrictions set by the emission constraint, (1), and at the same time results in an acceptable distribution of costs. In order to do this, the regulator must know the agents' response to the allocation rules given by (12).

6 Permit trading with a dominant agent and an adjustable allocation rule

The dominant agent seeks to maximize its income from emissions plus the income from selling permits, given its emission constraints and the inverse demand function for permits given by (8).

$$\max_{e_M, q} \Pi_M(e_M) = R_M(e_M) + p(e_F)q \tag{15}$$

s.t. (1) and (14).

Inserting for q from the monopolist's emission constraint, (14) and inserting for e_F from the total emission constraint (1), we can rewrite the monopolist's maximizing problem :

$$\max_{e_M} \Pi_M(e_M) = R_M(e_M) + p(Q - e_M) \cdot \left[Q_M^1 + Q_M^2 - \beta \left[p(Q - e_M) - \overline{P} \right] - e_M \right] \tag{16}$$

The first order condition of this optimization problem is:

$$R_M'(e_M) = \frac{\partial p}{\partial e_F} \cdot q + p - p\beta \frac{\partial p}{\partial e_F} \tag{17}$$

The second order condition of this maximization problem is given by:

$$R_M''(e_M) = \frac{\partial^2 p}{(\partial e_F)^2}(\beta p - q) - 2\frac{\partial p}{\partial e_F}(1 - \beta \frac{\partial p}{\partial e_F}) < 0 \tag{18}$$

If the monopolist's profit function is concave in e_M, (18) is satisfied, and we have a unique solution to the monopolists' profit maximizing problem. If the monopolist's profit function is not concave, it becomes difficult for the regulator to achieve a cost-effective distribution of emissions through β because the monopolist's choice of emission (depending on β), is discontinues[11]. We will in the following ignore that problem by assuming that the monopolist profit function is concave in $e_{M.}$ (Concavity will for instance apply with linear marginal income functions, which implies $R'''_F(e_F) \equiv \frac{\partial^2 p}{(\partial e_F)^2} = 0$).

Let $e_M{}^{AD}(\beta)$ be the solution to (17).

From the first order condition of the maximization problem (17), we observe that when β is equal to zero, that is, when the allocation of permits is not dependent on the permit price, we get same first order condition as derived in (11), where we concluded that the fringe emits too little and the monopolist emits too much compared to first best. The question is whether we can find a correction of the endowment of permits for the second round of allocations that leads to a cost-effective solution. This is a solution where $p = R'_j(e_j)$.

7 The optimal design of the allocation rules for permits

As mentioned above, the regulator aims to find a value for β which would maximize the total income from emissions, given the emission constraint, and at the same time lead to an acceptable distribution of costs between agents. The problem the regulator faces is illustrated in the figure below with linear marginal income functions. The marginal income functions for each agent ($R'_F(e_F), R'_M(e_M)$), and the marginal revenue functions for the monopolist in the situation with no intervention and in the situation where the adjustable allocation rule is used ($MR(e_M)$ and $MR(e_M(\beta))$ respectively) are drawn in the figure. Without any intervention, $p = p^{NI}$ and $e_M = e_M^{NI}$ in equilibrium (found where $MR(e_M) = R'_M(e_M)$). This will, as shown in section 4 lead to the dominant agent selling too few permits in order to drive up the permit price, which will make the distribution of emissions across agents non cost-effective. In addition, the distribution of

[11] This problem is discussed in Guesnerie and Laffont (1978).

costs across agents is not what was preferred. If the regulator chooses to use the adjustable allocation rule to correct these unwanted effects, the problem he faces would be to find a value for β that would lead to a cost-effective outcome and the desirable distribution of costs; that is, he will need to find a value of β that leads to that $p^{AD} = \overline{P}$ and $e_M = e_M^*$. This is achieved when, in equilibrium, the marginal revenue for the monopolist of selling one more emissions unit ($MR(e_M(\beta))$) equals the marginal income for the fringe of buying that unit ($R_F'(e_F)$), see figure 1.

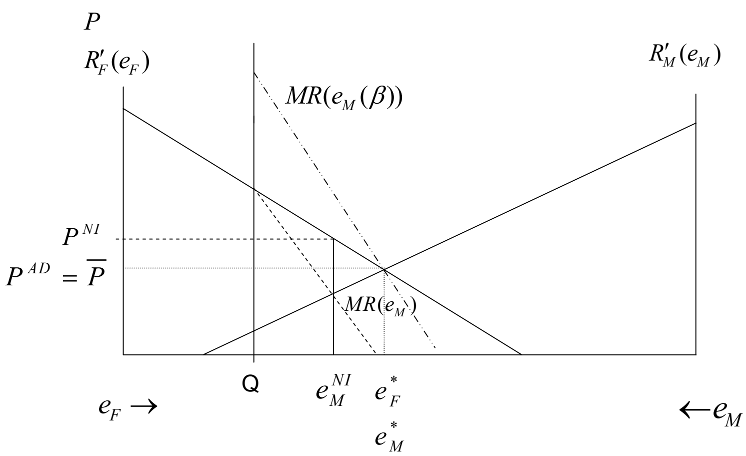

Figure 1

In the following, we show how the total income is influenced by an increase in β, and show the characteristics of the optimal β. If the derivative of the total income with respect to β is positive, allocating more permits to the fringe when the price of permits exceeds the competitive price would mean that the total income increases. Hence, we would approach a competitive outcome. The total income of the agents (TR) is a function of the total emission constraint, *Q*, and the distribution of emission across agents $e_M{}^{AD}(\beta)$). Hence, *TR* is given by:

$$TR(\beta) = R_F(Q - e_M{}^{AD}(\beta)) + R_M(e_M{}^{AD}(\beta)) \tag{19}$$

We find that:

$$\frac{\partial TR}{\partial \beta} = \frac{\partial e_M{}^{AD}(\beta)}{\partial \beta}\left(-\frac{\partial R(e_F)}{\partial e_F} + \frac{\partial R(e_M)}{\partial e_M}\right) \tag{20}$$

We see that the second part of the expression of the right hand side of equation (20) will be negative when $R_F'(e_F) > R_M'(e_M)$, as is the case when the monopolist exercises market power in the permit market. Further, we find from total differentiation of (17) that

$$\frac{\partial e_M{}^{AD}(\beta)}{\partial \beta} = -\frac{\dfrac{\partial^2 \Pi}{\partial e_M \partial \beta}}{\dfrac{\partial^2 \Pi}{(\partial e_M)^2}} = -\frac{\dfrac{\partial p}{\partial e_F}(2p - \overline{P})}{A} < 0$$

where A is the expression for the second order condition for profit maximization, which we have assumed is negative. Hence,

$\dfrac{\partial TR}{\partial \beta} > 0$ when $R_F'(e_F) > R_M'(e_M)$, which implies that a first best solution could be achieved with a sufficiently large increase in β. This means that β should be increased until cost effectiveness is achieved, i.e. where

$$R_F'(Q - e_M{}^{AD}(\beta)) = R_M'(e_M{}^{AD}(\beta)) \tag{21}$$

Let β^* be the solution (21). This leads to a cost effective distribution of emissions, and the equilibrium price would equal the competitive price ($p(e_F) = R_j'(e_j^{AD}(\beta^*) = \overline{P}$).[12]

Recall that Q_j^* is the allocation of permits that fulfills the regulator's preferred distribution of costs between the agents when $p = \overline{P}$. When $\beta = \beta^*$, the competitive

[12] We see from the monopolist's first order condition (17) and (14), that the optimal β must satisfy:

$$\beta = \frac{q}{\overline{P}} = \frac{Q_M^1 + Q_M^2 - \beta\left[p(Q - e_M(\beta, \overline{P}) - e_M(\beta, \overline{P})\right]}{\overline{P}}$$

price (or $\overline{P}$) will be realized. In this situation, the regulator could achieve its preferred distribution of costs between the agents by setting $Q_j^1 + Q_j^2 = Q_j^*$. This implies that with a dominant agent that acts as a monopolist, we could reach a cost-effective distribution of emissions between agents while at the same obtaining a preferred distribution of abatement costs. Furthermore, if the dominant agent acts as a price taker (see footnote 3), the equilibrium price in the market would be the competitive price (which is not influenced by β). And the regulator would realize its preferred distribution of cost as long as $Q_j^1 + Q_j^2 = Q_j^*$.

From the discussion above we derive the following proposition;

Proposition 1:

A permit allocation system that allows for adjustments of permit allocations can be designed to achieve a cost-effective solution for any preferred distribution of cost across agents, both when the dominant agent exercises market power and when it acts as a price taker.

8 The effect of a regulator's uncertainty about the agents' income from emissions

We showed in the previous section that under complete information about the agents' income from emission, the regulator could achieve the first best distribution of emissions across agents with the adjustable allocation rule (given by (12)). However, if there is uncertainty regarding the agents' abatement cost functions, the regulator may miscalculate the cost-effective distribution of emissions across agents and hence miscalculate the cost-effective permit price $\overline{P}$. The question is, of course, how this uncertainty would affect our conclusions in the previous sections. Would total costs be reduced with the adjustable allocation rule compared to a situation where the regulator does not intervene in the permit market?[13]

[13] This is the case described in section 4.

It can be shown that:[14]

Proposition 2

If the agent's income from emissions turns out to be different than what the regulator expected, then the adjustable allocation rule will not lead to a cost-effective distribution of emissions.

Further, in general one cannot rule out the possibility that the adjustable allocation rule would lead to higher total costs of reaching the emission target compared to the non-intervention case. It can be shown that:[15]

Proposition 3

If the agents' income from emissions deviates substantially from what the regulator expected when determining the value for $\overline{P}$ and β^*, we cannot rule out the possibility that the adjusted allocation rule would lead to higher total costs of reaching the emission target (Q) than choosing to not intervene in the permit market.

However, if the non-intervention case leads to large inefficiencies in the distribution of emissions across agents, and there are not too large uncertainties concerning the agents' marginal income from emission, the adjustable allocation rule leads to less total costs than under no intervention. This situation is illustrated in figure two with linear marginal income functions:

[14] This proposition is proved in the appendix for the case when the agents' income functions are represented by constant marginal shifts in these functions.
[15] This proposition is proved in the appendix for the case when the agents' income functions are represented by constant marginal shifts in these functions.

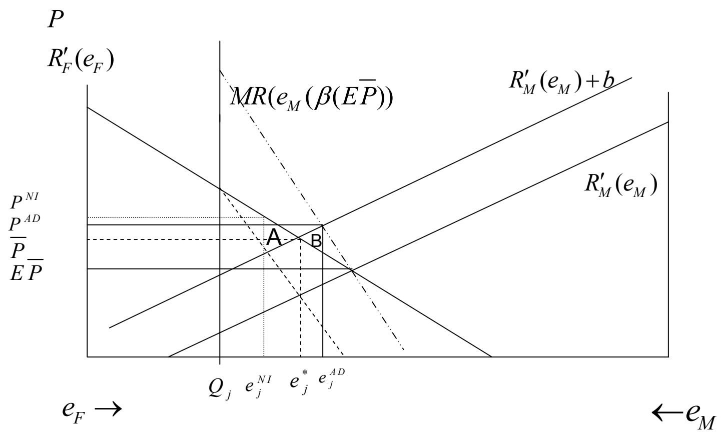

Figure 2

In figure 2, the correct income function for the monopolist is given by $R_M(e_M)+b$, whereas $R_M(e_M)$ is the income function the regulator expects that the monopolist has. $E\overline{P}$ is the competitive price that the regulator expects. The deadweight loss of not intervening in the market is given by triangle *A* in the figure, whereas the deadweight loss of using the adjustable allocation rule with uncertainty in the marginal income functions of the monopolist is given by triangle *B* in the figure. For the cost functions depicted in figure 2, total costs of the adjustable allocation rule would be less than the total costs of not intervening in the market (B<A). However, as given by proposition 3 this would not always be the case.

In addition, with uncertainty about the agents' income from emissions, a different distribution of costs across the agents than anticipated by the regulator will be the result. How large the deviation between the anticipated and the realized distribution of costs will be will depend on the magnitude of the uncertainties. Hence, an investigation into the magnitudes of the uncertainties regarding the agents' marginal income from emissions is therefore necessary before the allocation rule is chosen. This should be done to find out both how large the deviation between the anticipated and the realized distribution of costs between agents could be, and to get an indication of what kind of allocation scheme to choose – the adjustable allocation rule or the non-intervention scheme.

9 Concluding remarks

Hahn (1984) shows that it is possible to reduce the cost ineffectiveness caused by a dominant agent operating in a permit trading market by redistributing permits between agents. Further, it would also be possible to introduce an efficient subsidy of the monopolist's output to achieve a cost-effective outcome. However, these instruments could be impossible to use when there are constraints on the distribution of costs between agents that could limit the possibilities of manipulating the distribution of permits or transfers to a dominant agent. In this paper, we have analyzed how the regulator can fulfill distributional constraints while at the same time ensuring cost effectiveness when the only mechanism for achieving this is the allocation of permits between the agents.

We have shown that a permit allocation system which allows for adjustments in the allocations can be designed to lead to a cost-effective solution both when the dominant agent exercises market power and when it acts as a price taker. This so-called adjustable allocation rule will also ensure the preferred distribution of costs between agents. These results are derived for the case when the regulator and the agents have perfect information about one another's income from emissions. When the regulator over- or underestimates the agents' income from emissions and hence estimates a competitive permit price which deviates from the true competitive price, we are not guaranteed that intervening through adjusting the allocations will lead to lower costs than choosing to not intervene. However, if no intervention results in large inefficiencies because of agents exercising market power, and there are only small uncertainties about agents' income from emissions, the adjusted allocation rule will lead to lower total costs than choosing to not intervene in the permit market. If estimates of the competitive permit price and the agents' income of emissions can be based on experiences with the permit trading system, this could reduce the uncertainties and be used when allocating permits according to the adjustable allocation rule. These experiences could make it more likely that intervening through an adjustable allocation rule would lead to lower costs than choosing to not intervene.

The regulator could also choose to intervene in the permit market by setting a maximum price of permits. When there is no uncertainty about the agents' income from emissions, cost effectiveness could be achieved through a maximum price system. If the maximum price is set equal to the competitive price, the monopolist would be prevented from exploiting its market power. In this case, a system with a maximum price on permits would lead to the same results regarding cost-effectiveness and the distribution of costs between agents as the system where the allocation rule is adjusted over time. However, when there is uncertainty about the agents' income from emissions, setting a maximum price could mean that the market does not clear. For instance, if the regulator underestimates the marginal income from emissions that the monopolist faces, the maximum price would be set too low to ensure market clearance, and an excess demand for permits would be the result. Market clearance would, however, be achieved with the adjusted allocation rule.

The adjustable allocation rule suggested in this paper could, for instance, have relevance in a post-Kyoto agreement. If such an agreement uses the allocation of permits to induce participation from other countries, such as China, there is a risk that these countries could exercise market power in the permit market, and that we would face a cost-ineffective system. In this situation there could be grounds to introduce adjustments of the permit allocations to both secure the intended distribution of costs between the agents, and to reduce the cost-ineffectiveness from agents exercising market power. Before introducing a so-called adjustable allocation rule, an investigation into the magnitude of uncertainties about the agents' income from emissions should be made. In a post-Kyoto agreement, the experiences from the emission trading system in the Kyoto period could be used in this investigation to give indications about the agents' income from emissions.

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Appendix: Proofs of propositions 2 and 3

To prove propositions 2 and 3, we consider a situation where the regulator announces the values for $\overline{P}$ and β at the beginning of the emissions trading period. The regulator does not make changes in either $\overline{P}$ nor β during the emission trading period.[16] The fringe and the monopolist have (or gain) complete information about each other's abatement costs when trading begins.

In order to examine the impact of the regulator's miscalculation of the agents' income from emissions, we include shift parameters (*a* and *b*) in the monopolist's and the fringe's income functions of emissions. Thereafter we consider the impact on the distribution of emissions across agents when these shift parameters differ from what the regulator expected when $\overline{P}$ and β were chosen. That is, $R_M(e_M)$ and $R_F(e_F)$ are substituted by $\tilde{R}_M(e_M,a)$ and $\tilde{R}_F(e_F,b)$. To simplify our presentation, we consider constant marginal shifts in the agent's income functions[17]. That is,

$$\frac{\partial \tilde{R}_M(e_M,a)}{\partial e_M} = \frac{\partial R_M(e_M)}{\partial e_M} - a \tag{22}$$

$$\frac{\partial \tilde{R}_F(e_F,b)}{\partial e_F} = \frac{\partial R_F(e_F)}{\partial e_F} - b \tag{23}$$

When the regulator determines $\overline{P}$ and β, it assumes *a* and *b* to be zero. With the marginal income functions given by (22) and (23), this means that that the regulator overestimates (underestimates) the agents' marginal income of emissions when *a* or *b* are positive (negative).

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[16] If the regulator had access to more information during the trading period, the values of $\overline{P}$ and β could be updated over time, and the cost ineffectiveness due to the uncertainty could be reduced/disappear. However, with changes in the allocation system over time, lobbyism could be a result. The monopolist could also manipulate the system by claiming to have high costs (sell few permits) in order to induce a change in the $\overline{P}$ and β over time. (Asymmetric information about the monopolist's abatement cost could be dealt with by the use of more sophisticated incentive schemes than we consider. See for instance Laffont and Tirole (1993). That is, however, beyond the scope of this paper). In addition, changes in $\overline{P}$ and β would lead to more unpredictability of the conditions that the permit trading agents operate within, and could thus be politically difficult to implement.

[17] This simplification does not alter our qualitative results.

In order to compare the effect of uncertainty on the different permit systems discussed in this paper, it is necessary to derive the impact on optimal emissions when there is shift in the agents' marginal income from emissions.

The cost-effective response to shifts in abatement costs

A cost-effective distribution of emissions implies that marginal income from emissions is equalized across agents, that is

$$\frac{\partial \tilde{R}_F(e_F, b)}{\partial e_F} = \frac{\partial \tilde{R}_M(e_M, a)}{\partial e_M} \tag{24}$$

where $e_F = Q - e_M$

Let $e_M^*(a,b)$ be the solution to (24).

We find from total differentiating (24) (and from (23) and (22)), that

$$\frac{de_M^*(a,b)}{da} = \frac{1}{A^*} < 0$$

and

$$\frac{de_M^*(a,b)}{db} = -\frac{1}{A^*} > 0, \tag{25}$$

where

$$A^* = R''_M(e_M) + R''_F(e_F) < 0$$

Hence, an increase in *a/b* (that is, a reduction in marginal income from emissions for the monopolist/fringe) implies that the cost-effective emission level for the monopolist has decreased/increased.

We also see that an identical shift in both agents' marginal income functions would leave the optimal emissions level from the monopolist unchanged. Hence:

$$\frac{de_M^*(a,b)}{da} + \frac{de_M^*(a,b)}{db} = 0 \tag{26}$$

Responses to shifts in abatement costs under the adjustable allocation rule and the no-intervention case

Let ${e_M}^{AD}(\beta, a, b)$ denote the solution to the monopolist's optimization problem under the adjustable allocation rule, given by (16), when $R_M(e_M)$ and $R_F(e_F)$ are substituted by $\tilde{R}_M(e_M, a)$ and $\tilde{R}_F(e_F, b)$. That is, ${e_M}^{AD}(\beta, a, b)$ is the solution to (27):[18]

$$\begin{aligned} &(R_M'(e_M)-a)-R_F''(e_F)\cdot q-(R_F'(e_F)-b)\left(1-\beta R_F''(e_F)\right)=0 \\ &where \\ &q=\left[Q_M^1+Q_M^2-\beta((R_F'(e_F)-b)-\overline{P})-e_M\right] and\ e_F=Q-e_M \end{aligned} \tag{27}$$

Furthermore let $e_M^{NI}(a,b)$ denote the solution to the monopolist's optimization problem under no intervention, given by (10), when $R_M(e_M)$ and $R_F(e_F)$ are substituted by $\tilde{R}_M(e_M, a)$ and $\tilde{R}_F(e_F, b)$). That is, $e_M^{NI}(a,b)$ is the solution to (28):

$$\begin{aligned} &(R_M'(e_M)-a)-R_F''(e_F)\cdot q-(R_F'(e_F)-b)=0 \\ &where \\ &q=\left[Q_M^1+Q_M^2-e_M\right] and\ e_F=Q-e_M \end{aligned} \tag{28}$$

From total differentiating of the first order condition under the adjustable allocation rule, given by equation (27), the following impacts of shifts in the agents' marginal income from emissions are derived;

$$\begin{aligned} &\frac{de_M^{AD}(\beta,a,b)}{da}=\frac{1}{A^{AD}}<0 \\ &and \\ &\frac{de_M^{AD}(\beta,a,b)}{db}=-\frac{1-2\beta R_F''(e_F)}{A^{AD}}>0 \\ &where \\ &A^{AD}=R_M''(e_M)+2R_F''(e_F)\cdot(1-\beta R_F''(e_F))+R_F'''(e_F)\cdot(q-\beta(R_F'-b)) \end{aligned} \tag{29}$$

[18] Note that (27) and (28) correspond to (17) and (11) respectively when $R_M(e_M)$ and $R_F(e_F)$ are substituted by $\tilde{R}_M(e_M, a)$ and $\tilde{R}_F(e_F, b)$), and the expression for $p(e_F)$ given by (8) is inserted.

From total differentiating of the first order condition under the no-intervention case, given by equation (28), the following impacts of shifts in the agents' marginal income from emissions are derived:

$$\frac{de_M^{NI}(a,b)}{da} = \frac{1}{A^{NI}} < 0$$
and
$$\frac{de_M^{NI}(a,b)}{db} = -\frac{1}{A^{NI}} > 0 \qquad (30)$$
where
$$A^{NI} = R_M''(e_M) + 2R_F''(e_F) + R_F'''(e_F) \cdot q$$

Note that A^{AD} and A^{NI} are the expressions for the second order conditions for profit maximization which we have assumed are negative.

Proof of proposition 2:

We see from (25) and (29) that $A^{AD} \neq A^*$, such that $\frac{de_M^*(a,b)}{da} \neq \frac{de_M^{AD}(\beta,a,b)}{da}$, and $\frac{de_M^*(a,b)}{db} \neq \frac{de_M^{AD}(\beta,a,b)}{db}$ (except by chance). □

Proof of proposition 3:

Consider the case where there is a constant and identical shift in the monopolist's and fringe's marginal income from emissions, that is $da = db$. We know from (26) that cost-effective change in the seller's emissions following from such a shift is zero because $\frac{\partial e_M^*(a,b)}{\partial a} + \frac{\partial e_M^*(a,b)}{\partial b} = 0$. The change in the monopolist's emissions following from the shifts is also zero in the case where the regulator does not intervene in the permit market. (We see from (30) that $\frac{\partial e_M^{NI}(a,b)}{\partial a} + \frac{\partial e_M^{NI}(a,b)}{\partial b} = 0$). However, we see from (29) that

$\frac{\partial e_M^{AD}(\beta,a,b)}{\partial a}+\frac{\partial e_M^{AD}(\beta,a,b)}{\partial b}=\frac{2\beta R_F''(e_F)}{A^{AD}}>0$. The monopolist increases its emissions under the adjustable allocation rule, while emissions are held constant under the no-intervention case and under the cost-effective outcome. Hence, for sufficiently large (identical) shifts in the agents' marginal abatement costs, relative to what the regulator expected, the total costs of reaching the emission target Q might be higher with the adjusted allocation rule than under the no-intervention case. This would, for instance, be the case if the shift in the cost functions led to an increase in emissions from the fringe that was larger than the difference in emissions between the no-intervention case and the cost-effective solution, that is, if $\frac{2\beta R_F''(e_F)}{A^{AD}}\cdot da > e_M^{NI}(a,b)-e_M^{*}(a,b)$.

□