
Optimal Emission Levels
When Abatement Costs Are Private Information

By

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Abstract

Firms are generally reluctant to reveal their true marginal costs for environmental abatement. Depending upon the policy instruments used by the regulator, firms may even seek to misrepresent their abatement costs in order to gain a competitive advantage. This paper shows how the regulator can induce truth revealing behavior by firms in the emission permit market.

The aggregate optimal emission level of a particular pollutant is then found by comparing the market price for emission permits with the inferred price from the known marginal damage function for the same pollutant. The resulting aggregate emission level is shown to be a second-best Pareto-optimal allocation.

In addition to showing how to obtain optimal emission levels when firms are unwilling to reveal their true abatement costs, the paper gives insights regarding the design of emission permit markets, and the limitations and possibilities of such markets.

Key words: resource allocation mechanisms, optimal emission levels, second-best Pareto-optimality, welfare economics.

1 Introduction

The objective of this paper is to devise a method to obtain optimal emission levels by setting up new institutions that are informationally feasible and less costly to operate. It is assumed that firms are reluctant to disclose information about their cost structure and that the social damage function from emissions is known. By establishing markets for emission permits, the proposed method makes it possible to determine whether the imposed emission levels are too restrictive or too lax when the individual firms’ abatement cost are unknown to the regulatory agency\(^1\). The emission permit markets are to be set

\(^1\) The regulatory agency (also denoted as the planner or just the "agency") represents the public’s interests and seeks to maximize societal welfare.
up like a stock exchange. The regulatory agency is then able to compare the inferred
prices at the chosen aggregate emission levels with the observed prices for various
emission permits.

The next two sections outline the proposed mechanism and compare it with other
mechanisms that have been suggested on for obtaining optimal emission levels. In the
succeeding section the agents, their characteristics and objectives are described in a
framework of resource allocation mechanisms (RAMs). Next, the scheme is presented in
a model-context. Attention is given to the incentive compatibility and the informational
feasibility of the proposed scheme. Other important aspects of the model are discussed,
including how often should quotas be adjusted and the problem of non-participation (see
Roberts, 1982; Hahn and Noll, 1982; Hahn, 1983 and 1989; Atkinson and Tietenberg,

2 An Outline of the Proposed Mechanism

The proposed mechanism model indicates how markets for emission permits can be
used to obtain the optimal aggregate emission level when:

(i) society’s damage function for emissions, D(Z), is known, and

(ii) firms are reluctant to disclose their true marginal cost of reducing emissions.

Then by comparing the inferred price with the observed price at the chosen aggregate
emission level for a particular pollutant, the regulatory agency can determine the adequacy
of the chosen aggregate emission quota. A situation where the aggregate emission quota
is too high is depicted in Figure 1:
Figure 1: Aggregate emissions under transferable quotas: The issued aggregate emission quota ($Z^o$) is too large. $p^i$: price implied from the marginal damage curve at the $Z^*$ emission level, $p^o$: observed price at the $Z^o$ emission level, and $P(Z)$ the price curve of emission permits at various levels of emissions. $Z^*$ denotes the optimal aggregate emission level.

The converse situation would arise if $Z^o < Z^*$, as $p^o > p^i$. This discrepancy between the implied price from the damages of pollution and the observed (actual) price for pollution permits signals to the regulatory agency whether the aggregate quota, $Z^o$, of a particular pollutant is too small or too large. Note that under the proposed scheme the regulatory agency does not need to know the firms’ abatement costs.

For the suggested emission permit market to work, it is only necessary (i) that each firm can obtain its own abatement costs, (ii) that firms participating in the emissions trading market do not disclose information to other (competing) firms or the regulatory agency about their own abatement costs, and (iii) that firms can increase their profits by participating in the market. To reduce the informational costs to the participating firms, the market prices for various emission permits must be publicly known. This reduces the firms’ costs of participating in the market. To avoid important information being given to competing firms, traders in the market must be able to remain anonymous. By constructing the emission permits markets like a stock exchange, these two conditions are satisfied, thus increasing the likelihood of participation in the market.
3 A Comparison with Other Mechanisms to Achieve Optimal Emission Levels

Except in the case of publicly known abatement costs (Montgomery, 1972; Baumol and Oates, 1988), little work has been done to determine the optimal level of emissions when abatement costs are not publicly known. Notable exceptions are Roberts and Spence (1976), Kwerel (1979) and Dasgupta et al. (1980). Table 1 presents an overview of the various approaches regarding (i) each firm’s incentives not to mislead the regulatory agency, and (ii) the informational requirements of these various approaches.

**Table 1: Incentive compatibility and informational requirements of various methods to obtain optimal aggregate emission levels.**

<table>
<thead>
<tr>
<th>Mechanisma</th>
<th>Incentive compatibleb</th>
<th>Marginal damage function</th>
<th>Individual firm’s marginal abatement costs</th>
<th>Informatio-</th>
<th>Literature on the mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pigouvian taxes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Baumol &amp; Oates (1988)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pearce (1986)</td>
</tr>
<tr>
<td>Iterated Pigouvian</td>
<td>Noc</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Siebert (1987)</td>
</tr>
<tr>
<td>taxes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emission permits</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Dales (1968)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Baumol &amp; Oates (1988)</td>
</tr>
<tr>
<td>Mixed systemsd</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Roberts &amp; Spence (1976)</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Kwerel (1977)</td>
</tr>
<tr>
<td>Ambient permits</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Montgomery (1972)</td>
</tr>
<tr>
<td>Pollution offset</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Krupnick, Oates &amp; van De Verg (1983)</td>
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<td>permits</td>
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<td></td>
<td></td>
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<td>McGartland &amp; Oates (1985)</td>
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<tr>
<td>Command and control</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Baumol &amp; Oates (1988)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pearce (1986)</td>
</tr>
<tr>
<td>Groves-mechanisms</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td></td>
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<td></td>
<td></td>
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<td>Groves &amp; Loeb (1975)</td>
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<tr>
<td>Extended Groves-</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Dasgupta, Hammond &amp; Maskin (1980)</td>
</tr>
<tr>
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<tr>
<td>Contracts</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Xepapadeas (1991)</td>
</tr>
</tbody>
</table>

Remarks: (a) For a further look of the various pollution standards/types of emission permits, see Joeres and David (1983, pp. 267-270) and Baumol and Oates (1988).
(b) Incentive compatibility in this connection means that firms have incentives to choose their expected least cost approach to abatement control and not engage in actions to mislead the regulatory agency. All mechanisms require an appropriate monitoring system to ensure that emissions are not unreported.
(c) Opens for strategic behavior on behalf of the firms.
(d) The mixed systems include using both transferable permits and Pigouvian taxes or effluent subsidies.
(e) Information about abatement costs needed to formulate the optimal contract between the regulatory agency and the firm.

The mixed approaches (Roberts and Spence, 1976; Kwerel, 1979) and the extended
version of the Groves-type mechanism (Dasgupta et al., 1980) are the only types of mechanisms in Table 1 that are both incentive compatible (see table footnote (b)) and do not require that the agency has information about the individual firm’s abatement costs.

One problem with the mixed system of Pigouvian taxes and emission permits (Roberts and Spence, 1976), is that the Pigouvian tax needs to be adjusted several times to lead to the optimal emission level, $Z^*$. Their method is therefore subject to the same criticism as that of a system of iterated Pigouvian taxes.²

Initially Kwerel’s (1977) method of a mixed subsidy and emission permits is not hit by this criticism. Kwerel (1977:600) argues that "... a central desirable feature of the mixed effluent charge-license plan is its ability to hit the right point once-and-for-all." This point of view does not consider technological progress, implying gradually lower abatement costs over time, and thus that the optimal emission level is likely to change with time. In addition Dasgupta et al. (1980:858) criticize Kwerel’s approach (i) for depending on perfect competition in the emission permit market, (ii) for requiring pollutants from different firms to be perfect substitutes in the damage function for emissions, and (iii) because truthfulness is only a dominant strategy if each firm believes that the other firms are telling the truth.

The validity of the approach of Dasgupta et al. (1980) hinges on the notion that the distribution of individual firms’ abatement costs is perceived to be independent and random among firms. This assumption may break down when technological progress takes place, thus requiring new rounds of communication between the agency and the firms and new tax schedules to be developed.

² One difficulty with iterated Pigouvian taxes is that firms may have chosen their production/abatement technology on the basis of the initial Pigouvian tax. As the fee is adjusted, this technology choice may no longer be optimal from the firms’ perspectives. If technological adjustments are costly, repeated adjustments may cause losses which are larger than the incremental benefits derived from approaching the optimal emission level $Z^*$. 

Marketable Emission Permits and Participation in Emissions Markets

Hahn (1989) argues that the constraints implicit in a system of ambient or pollution offset permits make the permit market complex. According to Hahn, one reason for the lack of participation in permit markets using ambient or pollution offset permits is their complex design. The advantage of an ordinary emission permit market is that it works just like any other input factor market. Thus the firms are dealing with a familiar concept, reducing the chances for misunderstanding and lowering implementation costs. This provides some of the motivation behind this paper: keep the mechanism simple.

4 Resource Allocation Mechanisms

Any economic system or mechanism is a communication process, where each agent transmits messages to which other agents respond according to their self-interest. A successful resource allocation mechanism (RAM) utilizes this, so that each agent without necessarily understanding the complete process, is induced to cooperate in the determination of a satisfactory bundle of goods and services (Campbell, 1987). Under this definition the proposed system is a RAM.

Campbell lists the following desirable properties of RAMs; (i) individual rationality, (ii) informational viability and efficiency, (iii) incentive compatibility and (iv) Pareto-optimality. The importance of these properties, and necessary modifications due to conflicts between them will be demonstrated.

*Individual rationality* requires that the suggested RAM generates allocations that make all the firms, $n \in N$, and all consumers, $i \in I$, at least as well off as they were initially. This property is also called the participation constraint (Rasmusen, 1989).

*Informational viability* is important because RAMs which do not satisfy this property
have informational requirements that exceed the available information. Any RAM that is not informationally viable may therefore not yield its intended outcome(s). Informational viability requires (i) that agents only use accessible information about the other agents, and (ii) that the amount of information is such that it can be treated (Campbell, 1987). Formally (i) is the privacy preserving property of the RAM, implying that only public information about one agent can be used by the other agents. The formal implication of (ii) is that the message space must be finite in Euclidian space. This means that the vector of information exchanged between the agents has a finite dimension.

*Informational efficiency* means that there exists no known RAM which satisfies the stated objectives at less cost of gathering and processing (Campbell, 1987).

*Incentive compatibility* means that it should be in the self interest of the firms to act in the prescribed way. Unfortunately joint incentive compatibility and Pareto-optimality are not always possible. This is due to the problem of manipulation.

**DEFINITION 1:** Manipulation means that an agent by not revealing his true preferences is able to increase his own welfare, resulting in a loss of welfare for the other agents.

The following theorem due to Hurwicz (1972) illustrates the importance of manipulation (Campbell, 1987:114):

**THEOREM 1:** Let $R'$ be a mechanism defined on a family of economic environments, the family of pairs of self-regarding utility functions that exhibit diminishing marginal rates of substitution everywhere. If for every environment within this family of environments, the mechanism $R'$ generates equilibrium allocations that are Pareto optimal and individually rational, then it can be manipulated.
The essence of the proof of Theorem 1 is that one agent can obtain increased utility (or profits) by manipulative behavior when all the other agents behave sincerely. Thus each agent is led to behave manipulatively, and the outcome is not Pareto-optimal. Consequently, if the policy maker opts for potential Pareto-optimal RAM, such an outcome is not guaranteed. Now suppose that the policy maker decides to opt for an incentive compatible RAM. Even if Pareto-optimality is not achieved, the proposed RAM will yield a predictable outcome, whose welfare properties can be evaluated.³

According to the theory of second best it is uncertain whether applying marginal cost pricing in the sectors under consideration will move the entire economy closer to the Pareto-optimum, unless the optimum conditions are met in the rest of the economy (Lipsey and Lancaster, 1956; Boadway and Bruce, 1984). In general the latter will not be the case. Thus Pareto-optimality may not be applicable in the case of RAMs seeking to correct for externalities. Spulber (1989) suggests replacing Pareto-optimality with Second-Best Pareto-Optimality (SBPO). Expressed in terms of the constrained indirect utility function, SBPO is defined as:⁴

DEFINITION 2: Second-Best Pareto-Optimality: Assume that to a certain externality vector, \( Z \), there exist certain prices and consumer incomes. Let \( p^a \) and \( p^b \) denote the price vectors from the externality vectors \( Z^a \) and \( Z^b \) respectively. In a similar fashion let \( X_i^a \) and \( X_i^b \) be the associated consumer incomes for the \( i \)th consumer.

An externality vector \( Z^a \) is SBPO if there exists no other externality vector \( Z^b \) such that 

\[
V_i(p^b, X_i^b \mid Z^b) \geq V_i(p^a, X_i^a \mid Z^a) \quad \forall \ i \in I \quad \text{and if } \exists \ i \in I \quad \text{such that} \quad V_i(p^b, X_i^b \mid Z^b) < V_i(p^a, X_i^a \mid Z^a).
\]

³ The problem of manipulation has been addressed by Romstad and Bergland (1997).

⁴ A definition of SBPO using the ordinary utility function is found in Spulber (1989, p. 355).
Informational viability and efficiency and incentive compatibility are required for the proposed RAM to yield a predictable outcome. Individual rationality is important to facilitate the implementation of the RAM. To evaluate any RAM, a welfare indicator is needed. SBPO is chosen as welfare indicator as it does not require correction of all inefficiencies in the economy, nor does it require individual utilities to be comparable.

PROPOSITION 1: Informational efficiency is a necessary criterion of Second-Best Pareto-optimality.

The modified desirable properties of a RAM are therefore;

(i) individual rationality,

(ii) informational viability and efficiency,

(iii) incentive compatibility, and

(iv) second-best Pareto-optimality.

5 Modelling the Emission Permit Market

In this section the model is treated more formally than in section two. The following versions of the model are presented:

− an atemporal version – to demonstrate the principles of the model, and

− a dynamic version – which gives additional insights pertaining to the organization of the emission permit markets.

The next two sub-sections present the economic framework in which the model is set. In the two succeeding sub-sections the atemporal and dynamic version of the proposed model are presented in more detail. The last two sub-sections of this section evaluate the proposed scheme in light of the criteria outlined for RAMs and look at some of the
problems that may arise in implementing and applying the proposed model.

The Economy

The economy consists of firms, consumers and government. Firms produce private goods. Government orders and pays for public goods. A sector of an economy concerns the production and consumption of a particular type of goods or services. Consumers seek to maximize utility from consumption of both private and public goods.

Any RAM must be viewed in conjunction with the environment, which consists of technology, preferences and institutions. The technology describes the firms’ production processes. The resulting constrained profit functions are derived using McFadden’s (1978) approach. Moreover it is assumed that the firms behave according to the putty-clay framework (Johansen, 1972). Preferences influence consumers’ choices. The basis for the welfare analysis is the indirect utility function, \( V_i(p,X_i) \), \( i \in I \), where \( I \) is the index set of consumers (Varian, 1984). Second-Best Pareto-Optimality (SBPO) is chosen as the welfare indicator. Institutions include the legal system and the organization of government.

Optimal Emission Levels in an Atemporal Setting

In the previous section on RAMs it was argued that SBPO is a suitable measure of

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5 Whenever the term “private goods” is used, it refers to goods and services that are rival and exclusive (Randall, 1983).

6 Whenever the term “public goods” is used, it refers to non-rival and non-exclusive goods and services (Randall, 1983).

7 The term "environment" refers to the economic environment.

8 Several other welfare indicators exist. These include Aggregate Money Metric Utility, the Bergson-Samuelson Social Welfare Function and Pareto-Optimality.
societal welfare given assumptions made about individual preferences. Using a principal-agent formulation (Rasmusen, 1989), the regulatory agency’s objective (the principal) is to choose an aggregate emission level, $Z = \sum_{n \in N} z_n$, where $N$ denotes the index set of the firms, such that SBPO is achieved. By the definition of SBPO, this implies:

$$\text{Agency: } \begin{cases} \text{Choose } Z \neq Z' \vspace{1em} \\ \text{s.t.} \vspace{1em} \end{cases} \begin{align*} V_i(p, X_i \mid Z) &> V_i(p', X'_i \mid Z') \forall i \in I \text{ and} \\ V_i(p, X_i \mid Z) &> V_i(p', X'_i \mid Z') \text{ for some } i \in I. \end{align*} \tag{1}$$

Assume non-homogeneous firms indexed by $n$ with $n \in N$. Also assume that each firm produces one good ($y$) and emits one pollutant ($z$). The cost function is assumed to satisfy the conditions given in the following lemma by McFadden (1978:13):

"Suppose the firm has an input-regular production possibility set with a producible output set $Y^*$ and input requirement sets $V(y)$ for $y \in Y^*$. Suppose that the firm faces competitive input markets with a non-negative input price vector $v$. Then the cost function exists for all $y \in Y^*$ and all non-negative $v$. Further, for each $y \in Y^*$, the (extended) cost function as a function of $v$ is non-negative, positive when $v$ is strictly positive and $y$ is non-zero, non-decreasing, positively linear homogeneous, concave and continuous".

By the duality theorem (McFadden, 1978:82-83) it then follows that the each firm’s profit function exists uniquely. Then the nth firm’s unconstrained single-period profit function can be expressed as:

Firm n: $\begin{cases} \text{MAX } y_n, z_n \vspace{1em} \\ \end{cases} \pi_n(y_n, z_n) = p_y y_n - C_j(y_n, z_n) \tag{2}$. 

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where \( p_y \) is the market price for the produced good, \( y \),
\( y_n \) is the \( n \)th firm’s output,
\( z_n \) is the \( n \)th firm’s emission level, and
\( C_j(\bullet) \) is the firm’s cost function of producing \( y_n \) with the emission level \( z_n \)
(which is not known to the regulatory agency).

The principal-agent formulation is then the game between the agency and the firms as
defined by [1] and [2]. When each firm is awarded an emission quota, \( z^0_n \), each firm must
solve the constrained maximization problem, [2] st. \((z^0_n - z_n) > 0\). This yields the
following Lagrangian:

\[
L = p_y y_n - C_j(y_n,z_n) + \lambda \cdot (z^0_n - z_n) \tag{3}
\]

Using the Kuhn-Tucker approach and assuming that the emission constraint is
binding, the most interesting first order condition of [3] is:

\[
\frac{\partial L}{\partial z_n} = -\frac{\partial C_j}{\partial z_n} - \lambda = 0 \tag{4}
\]

At the optimal product output level, \( \frac{\partial C_j}{\partial z_n} < 0 \). Consequently the firm maximizes its
profits where the marginal costs of abatement equals the shadow price of the constraint.
In the case of a permit market, this implies that each firm should buy or sell permits until
its shadow price of the constraint equals the market price for permits.

Thus under the atemporal transferable emission permit scenario, each firm will buy or
sell pollution permits until the cost of buying one more permit-unit equals the respective
firm’s marginal cost of pollution abatement. Assume that no firm cheats, that is, does not
emit more pollutants than its quota. Then the agency can compare the price on pollution
permits with the implied price at a \( Z \) level of emissions from the known marginal damage
curve of pollution to determine the optimality of the aggregate emission level, \( Z \), as
indicated by Figure 1.
This atemporal model illustrates the conditions for optimality of the aggregate emission level. The model does not describe the adjustment patterns leading to the optimal emission level, nor does it indicate the correct interpretation of the price of emission permits when firms are assigned and buy emission permits. To analyze these aspects in a proper fashion, a dynamic (intertemporal) model is needed.

A Dynamic Model for Optimal Emission Levels

Recall that \( p_i(Z_t) \) is inferred from the marginal damage function, and \( p_o(Z_t) \) is derived from the emission permit market. In the intertemporal case, the polluting firms buy permanent emission permits. Thus these permits need to be viewed as an investment. The price of the emission permits reflects this, and can not be used alone to infer the optimal emission level. Assume perfect capital markets. Also assume that the real interest rate, \( r \), is fixed and there is complete knowledge. Let all prices be real prices. By [4] and the above assumption, the criterion for optimality of \( Z_t \) can be restated as:

\[
p_i(Z_t) = r p_o(Z_t), \quad \forall \ t \in \{0,1,...,T'\} = T'
\]

Let \( \kappa \) equal \( r p_o \). Using a principal-agent formulation the mathematical expression of the intertemporal model becomes:

\[
\text{Agency: } \begin{cases}
\{ \text{Choose } \{Z_t \neq Z_{t+1}\}_{t \in T} \} \\
U_i(Z_t) \geq U_i(Z_{t'}) \quad \forall \ i \in I \quad \text{and} \\
U_i(Z_t) > U_i(Z_{t'}) \quad \text{for some } i \in I.
\end{cases}
\]

\[
s.t. \sum_{n \in N} z_{nt}^0 = \sum_{n \in N} z_{nt}^1 = Z_t
\]

\[
\text{Firms: } \begin{cases}
\{ \text{MAX } \{z_{nt}^1\}_{t \in T} \} \\
\sum_{t \in T} \beta^t [\pi_n(z_{nt}^1) - \lambda_t(z_t) \cdot (z_{nt}^0 - z_{nt}^1)]
\end{cases}
\]

where \( z_{nt}^1 \) is the nth firm’s post-trade level of emissions, \( z_{nt}^0 \) is the nth firm’s pre-trade allocation of emissions, and \( \beta \) is the discount factor \((1 + r)^{-1}\), where \( r \) is the interest rate.
From [6] it is evident that the sequence $\{\lambda_t(Z_t)\}_{t \in T}$ and thus the sequence $\{p^e_t\}_{t \in T}$ depends upon the solution of the firms’ problem of maximizing expected discounted profits. Let $\{z^*_n\}_{t \in T}$ denote the nth firm’s ex-trade profit maximizing solution of [6]. Further insights into the nature of the sequence $\{p^e_t(Z_t)\}_{t \in T}$ is obtained from looking at the nth firm’s cost minimization problem. By duality of the production function the following Lagrangian can be constructed:

$$L = \sum_{t \in T} B^t [C_j(y_{nt}, z^0_{nt}) + \lambda_t(Z_t) \cdot (z^0_{nt} - z^1_{nt})]$$

where $\{z^1_{nt}\}_{t \in T}$ denotes the nth firm’s ex-trade profit maximizing solution of [6].

The nth firm’s cost function of abatement, $j \in J$, is assumed to be well behaved (follows from McFadden, 1978), i.e. $\frac{\partial C}{\partial z^1_{nt}} < 0$ evaluated at $y^*_t$, the profit maximizing output level at time $t$. Thus the firm’s minimum cost choice of $z^1_{nt}$ occurs where:

$$\lambda_t(Z_t) + \frac{\partial \lambda_t(Z_t)}{\partial z^1_{nt}} \cdot (z^0_{nt} - z^1_{nt}) = \kappa_t = r p^e_t$$

where $\lambda_t(Z_t)$ is the Lagrangian multiplier of the ex-trade constraint, and

$$\frac{\partial \lambda_t(Z_t)}{\partial z^1_{nt}}$$

is the change in the product of the interest rate times the market price of permits as $z^1_{nt}$ changes.

The value of the shadow-price, $\kappa_t$, denotes the loss in profits due to the emission constraint. If $\kappa_t$ exceeds the left hand side of [8], the firm can reduce its costs by buying additional permits until [8] holds. Each firm’s sequence of ex-trade emission levels, $\{z^1_{nt}\}_{t \in T}$, denotes the solution of [8], and implies a sequence of emission permit prices, $\{p^e_t(Z_t)\}_{t \in T}$, provided each firm participates in the market according to [8]. Thus the optimality of the proposed scheme also depends upon whether the firms behave such that [8] is met or not. It remains to be shown that this also is the dominant strategy for the firms. Viewing the market for emission permits as a RAM yields some interesting insights into the requirement in [8], and thus into the feasibility of the proposed scheme.
Evaluating the Proposed System as a Resource Allocation Mechanism

The proposed RAM needs to be evaluated on these previously defined criteria for resource allocation mechanisms (see section four).

**Individual Rationality**

Suppose that the current emission level is individually rational to all agents in the economy. This implies that there exists no known RAM that would be able to correct for the externality without making at least one agent worse off. Consequently the externality would be Pareto-irrelevant\(^9\), and the optimal action is not to correct for the externality.

To make sense in this setting, the property of individual rationality needs to be modified to apply to any other RAM designed to reduce emissions to a certain level, \(Z'\).

Baumol and Oates (1988) show that a system of marketable permits is the least cost alternative to the firms for reducing pollution by any amount. Given emissions reductions are to take place, the proposed RAM system of marketable permits therefore meets the criterion of individual rationality from the firms’ perspectives.

**Informational Viability and Efficiency**

In the proposed system of marketable permits each firm only needs to know its own abatement costs and to observe the market price for emission permits. The former is needed for the firms to choose their cost minimizing emission levels under any scheme designed to reduce emissions. The latter is easily observed by all firms. Thus from the firms’ perspective the proposed system is informationally viable.

The message space for the regulatory agency consists of prices for emission permits,

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\(^9\) Pareto-irrelevant externality: any externality where the cost of removing or reducing the external effects outweigh the benefits of the change (Dahlman, 1979).
the overall level (set by the agency) of emissions at these prices and the consumers’
perceived disutility at this level of emissions. This message space is also finite.
Moreover, the proposed system does not require the agency access to the firms’ cost func-
tions, and is therefore privacy preserving. The scheme is therefore informationally viable
from the viewpoint of the agency.

By Proposition 1 informational efficiency is a necessary condition for the overall effi-
ciency of the proposed RAM. Any RAM seeking to reduce emissions to a certain level
requires the individual firm to know its own abatement costs. Assuming that the cost of
observing the market prices for permits is negligible, the proposed scheme is informa-
tionally efficient from the firms’ viewpoint.

The only informational costs incurred by the regulatory agency are (a) obtaining the
consumers’ valuation of the various levels of reduction in aggregate emissions and (b)
administering the market for permits. Informational efficiency from the perspective of the
regulatory agency therefore depends upon whether the costs indicated by (a) or (b) exceed
the informational costs of any alternative RAM satisfying the same objectives.

For a system of direct regulation or Pigouvian taxes to yield the optimal level of
emissions, $Z^*$, information about the public’s valuation of reduced emissions is needed.
The same information is required for the proposed system. In that respect the
informational costs of the suggested RAM does not exceed the informational costs of any
known alternate RAM.

The cost associated with operating an emissions permit market is the only remaining
factor which prevents the suggested RAM from being SBPO. It is reasonable to assume
that the costs of direct controls exceed these costs. Thus the suggested scheme is more
cost efficient than direct controls by assumption.

A system of Pigouvian taxes incurs considerable informational costs when the
bargaining costs of changing the fees are incorporated. As changes in the emission level is not assumed to be subject to negotiations, the proposed system of marketable emission permits does not have this problem. Under the suggested scheme, reductions in the overall pollution level can only take place by the agency or the public through the purchase of emission permits for retirement.

**Incentive Compatibility**

Incentive compatibility in the case of transferable emission permits has two dimensions. One problem in this aspect is the firms' compliance with the emission levels acquired. For now, this problem is assumed solved, i.e. each firm complies with its extra-trade quota.

**DEFINITION 3:** Strategic behavior in the emission permit market for the nth firm is any action different from the action defined by the nth firm’s demand curve for emission permits.

**DEFINITION 4:** A coalition of firms is a collection of firms which coordinate their strategies.

The aim of strategic behavior on behalf of any firm in the emission permit market is to increase its discounted profits. It will be shown that it is not profitable for any firm to behave strategically, alone or in a coalition. To prove that non-strategic behavior in the emission permit market is the dominant strategy for the firm, the following lemma (Spulber, 1989:353) is needed:

**LEMMA 1:** The market price for emission permits, $p^e_t$, is reduced with increased emissions.
PROPOSITION 2: The dominant strategy for any single firm is not to behave strategically.

Misiolek and Elder (1989) address the problem of strategic behavior in emission permit markets. They claim that procedures to discourage strategic overbuying on behalf of dominant firms in the emission permit market. The proof of Proposition 2 shows that the suggested mechanism addresses this problem, as both over- or underbuying are dominated strategies compared to non-strategic behavior.

DEFINITION 5: A stable coalition is a coalition where the expected profits of every firm in the coalition exceeds the expected profits of belonging to any other coalition or belonging to no coalition (Cornes and Sandler, 1986:96).

PROPOSITION 3: Any coalition of strategically behaving firms in the permit market is unstable as any member of the coalition has greater expected profits from non-strategic behavior.

Hurwicz (1959, 1973) shows that in a dynamic market where there is uncertainty about the environment, the dominant strategy of the firms is to participate in the market without behaving strategically. The environment is allowed to change over time, and the firms do not know which changes will take place. The existing prices in the market are based on the firms’ current information.

Hurwicz’s analysis applied to the emission permit market indicates it is in the firms’ self interest to participate in a market for emission permits without behaving strategically. More specifically, if the price a firm is offered for a permit for an emission quantity is higher than the firm’s marginal cost of reducing emissions, the dominant strategy for the firm is to sell emission permits.
Second-Best Pareto-Optimality

The suggested scheme is informationally efficient, a necessary condition for SBPO (Proposition 1). Propositions 2 and 3 show that the dominant strategy of the firm or a coalition of firms is to buy emission permits such that each firm’s stock of permits equals $z^*_n$ defined by the firm’s demand curve for emission permits. As firms will buy and sell permits such that [8] holds, it is possible for the regulatory agency to infer the optimal aggregate emission level, $Z_t^*$, by comparing the inferred price, $p^*_t$, from the damage function, $D_t(Z_t)$, with $r p^*_n$.

A system of marketable emission permits minimizes the producer’s cost of reaching an overall targeted level of emissions compared to a system of Pigouvian taxes or direct regulation (Baumol and Oates, 1988). This is equivalent to maximizing producers’ profits, given a certain emission level. The proposed system also ensures that the optimal level of emissions, $Z^*$, is reached, resulting in SBPO being achieved. This result follows from Spulber (1989). He showed that when the marginal costs of abatement equals its marginal benefits, the allocation is SBPO.

6 Discussion

In treating the proposed scheme as a RAM, some related and relevant issues have not yet been commented on or may need further comments. The following sub-sections address these issues.

The Regulatory Agency

The recognition of the existence of externalities that need to be corrected provides sufficient justification to fund the regulatory agency through ordinary taxes. This includes
providing the agency with sufficient funds to buy back permits in case the initial aggregate emission level is too high. An additional benefit from this way of funding the regulatory agency is that it reduces the incentives the agency may have to pursue own goals, thus introducing inefficiencies in the emission permit market. The rationale behind this argument is "the neutrality of lump-sum transfers".

The Adjustment of the Aggregate Quotas

Recall that the initial quotas given to the firms, \( z_0^i \), and the ex-trade quotas, \( z_1^i \), are equivalent to property rights. Thus any profit maximizing agent will sell emission permits if this leads to an increase in expected discounted profits. For the proposed scheme to work, it is important that the agency is not able to take away any permit without a level of compensation that increases the above mentioned profits. Barring institutional change, this means that any firm can not be forced to give up its quotas. This is consistent with the requirement that permits must be permanent (Palmisano and Brooks, 1990). Any downward adjustment in the aggregate quota thus requires the regulatory agency to buy back emission permits for retirement.

One unresolved question is how often the regulatory agency should intervene and attempt to buy back (or sell) additional permits. In this connection it is important to remember that the damage function is estimated, for example through contingent valuation methods. As such it has certain statistical properties. Thus the observed market price for pollution control can be inside or outside the \( 1 - \frac{\alpha}{2} \) confidence interval at the aggregate emission level \( Z_0^i \). An illustration of this phenomena is given in the following figure:
Figure 2: The market price for pollution permits times the interest rate may be inside ($\kappa^i$) or outside ($\kappa^o$) the $1 - \frac{\alpha}{2}$ confidence intervals of the estimated damage function (MD).

Thus one may conclude that the agency should only seek to adjust the aggregate emission level if $\kappa_t$ is significantly different from the inferred price from the damage function.

In an intertemporal model, one must also allow for the marginal costs of abatement or the public’s valuation of environmental amenities to change over time. For instance, due to technological progress, the firms’ cost of pollution abatement may decrease. Keeping in mind the statistical variability in the estimated damage function, this once again means that the regulatory agency should buy permits for retirement if $\kappa_t$ falls below the inferred price given by the damage function, $D_t(Z_t)$.

Participation in Emission Permit Markets

The experience with current markets for pollution permits is mixed, as firms have not always participated as expected (Roberts, 1982; Hahn and Noll, 1982; Hahn, 1989; Atkinson and Tietenberg, 1991). Hahn (1983, 1989) claims that some of this lack of participation may be due to the complicated nature of these markets (pollution rights had limited lifetime and needed to be renewed etc.). These are compelling arguments to keep
the markets for pollution permits as simple as possible. The proposed scheme does that. To the firms, the suggested pollution permit market operates like any other input market.

Enforcement

The proposed RAM does not deal with the problem of firms complying with their quota, $z_m$. Malik (1987) discusses the effects of compliance and non-compliance on the emissions permit market. Several monitoring and enforcement schemes can be combined with the suggested system of transferable emission permits to induce compliance. Some of these include Russell, Harrington and Vaughan (1986), and Russell (1990).

7 Concluding Remarks

The proposed system of transferable pollution permits, matched with the public’s valuation of pollution abatement, satisfies the desired properties of the resource allocation mechanism: (i) individual rationality, (ii) informational viability and efficiency, (iii) incentive compatibility (in the sense that firms will not seek to influence the market price for permits), and (iv) second-best Pareto-optimality. A necessary condition for SBPO to result is that the benefit (or damage) function entails both direct and indirect effects from emissions. Over time the abatement costs or the public’s perception of the damages incurred from emissions may change. The proposed system is well suited to deal with these phenomena.

Over time the marginal costs of abatement decrease with technological progress. This lowers the price on emission permits. One recent manifestation of this is the effect of the clean air act in the US. At its start the permit price per ton of SO$_2$ was one thousand dollars, while today – in 1998 – the permit price per ton is about seventy dollars, i.e.
about 7% of the permit price eight years ago. The experiences from the US clean air act to some extent also demonstrate the importance of the suggested scheme, as the sharp decline in the permit price could imply that the current aggregate SO$_2$ target of the clean air act is too high. By allowing the regulatory agency to buy back permits for retirement, aggregate emissions would decline and welfare enhancing improvements in environmental could be obtained.

The public’s concern about the damages from emissions over time may increase, or there could be accumulative effects from past emissions. In both cases this leads to a shift in the damage function to the left or the damage function becomes steeper. In either case, the old emission level is excessive. Observing the inferred price being higher than the market price times the capital costs, the regulatory agency can once more buy back emission permits for retirement until equilibrium is reached.

In the process of showing that the proposed system is incentive compatible with respect to participation in the emission permit market, additional insights have been gained regarding emission permit prices. Given a particular environment, the resulting emission permit price is consistent with firms maximizing their expected profits.

The key objective of this paper, to devise new institutions that are informationally feasible and less costly to operate, have been accomplished for the case when the regulatory agency does not know the firm’s costs of pollution abatement. It has been demonstrated that markets for emission permits constructed as suggested in this paper, is one such type of institution.
8 APPENDIX: Proofs

PROPOSITION 1: Informational efficiency is a necessary criterion of Second-Best Pareto-optimality.

PROOF: Suppose informational efficiency is not necessary for SBPO. Let $C_I(\bullet)$ denote the informational costs. Let there exist an externality vector, $Z'$, which is SBPO, while the proposed RAM, $R'$ is not informationally efficient. Also assume there exists another RAM, $R''$ which results in the same externality vector $Z'$ at less informational cost, i.e. $C_i(R'') < C_i(R')$. The difference in informational costs between the two RAMs is then $\Delta C_i(R', R'') = C_i(R') - C_i(R'') > 0$, which can be used to make some or all the agents better off. Then by the definition of SBPO, the RAM $R'$ is not SBPO. Q.E.D.

PROPOSITION 2: The dominant strategy for any single firm is not to behave strategically.

PROOF: The assumptions leading to definition of the cost function with externalities, $C_j(y_n, z_n)$, assure that the nth firm’s demand curve for emitting $z_n$ is single valued, i.e. for a given output level, $y_n$, there exists one and only one emission level. As the profit function is the convex conjugate of the cost function, it therefore follows that to the profit maximizing output level, $y_n^*$, there exists one emission level, $z_n^*$. Suppose one firm decides to behave strategically, and buys emission permits such that its stock of permits, $z_n' > z_n^*$. This action causes (i) the strategically behaving firm’s profits to be less than they would under non-strategic behavior, and (ii) the market price for permits to increase as the overall demand for permits increases by Lemma 1. With the increase in the permit price, the regulatory agency increases the aggregate emission quota, which again lowers the permit price. As the strategically behaving
firm already has an excess stock of permits, it will not benefit as much from this reduced permit price as the other firms. Consequently the expected discounted profits from strategic behavior for one firm are less than the expected discounted profits from non-strategic behavior. Q.E.D.

PROPOSITION 3: Any coalition of strategically behaving firms in the permit market is unstable as any member of the coalition has greater expected profits from non-strategic behavior.

PROOF: This follows directly from Proposition 2. As the expected profits from strategic behavior is lower than the profits from non-strategic behavior, any member of the coalition has incentives to pursue the profit maximizing behavior consistent with [8]. Thus the coalition is unstable. Q.E.D.
9 Bibliography


