E C O N O M I C S   B U L L E T I N

Citizens' demand for permits and Kwerel's incentive compatible mechanism for pollution control

Daniel English
University of Richmond

Andrew Yates
University of Richmond

Abstract

An interesting feature of pollution permit markets is that citizens may purchase permits to directly lower the levels of pollution. Kwerel's mechanism (Review of Economic Studies~1977) is not incentive compatible when citizens demand permits. We show that a modification of Kwerel's mechainism, the minimum-price mechanism, is incentive compatible when citizens demand permits, even in the case where there is uncertainty about the damages from pollution.

We thank seminar participants at the University of North Carolina Greensboro for helpful comments.
Citation: English, Daniel and Andrew Yates, (2007) "Citizens' demand for permits and Kwerel's incentive compatible mechanism for pollution control." *Economics Bulletin*, Vol. 17, No. 4 pp. 1-9
Submitted: January 24, 2007. **Accepted:** February 1, 2007.
URL: http://economicsbulletin.vanderbilt.edu/2007/volume17/EB-07Q20001A.pdf

1 Introduction

Kwerel (1977) presents a mechanism for pollution control that utilizes a competitive pollution permit market. In his model, the damage from pollution is common knowledge, but the firms' abatement costs are private information. The government asks the firms to submit their abatement costs and uses their responses to determine two parameters of the pollution permit market. The first parameter is the endowment of permits and the second parameter is a subsidy for reducing pollution below the number of permits held. Under the assumptions of his model, Kwerel's mechanism is strictly incentive compatible—firms have the incentive to tell the truth about their abatement costs. Although subsequent authors (Dasgupta et al. 1980, Lewis and Sappington 1995) analyze more general mechanisms for pollution control, Kwerel's mechanism retains prominence in the environmental economics literature and is often featured in textbook presentations (Kolstad 2000, Goodstein 2002).

Kwerel implicitly assumes that pollution permits trade only among the firms. A number of recent papers, however, consider the possibility that citizens harmed by pollution may participate in permit markets.[1] In these markets, citizens buy and "retire" permits to lower the quantity of pollution. Although the endowment of pollution permits is determined by the government, the actions of firms and citizens in the market determine the actual level of pollution.

We analyze the effects of citizens' demand for permits on Kwerel's mechanism. In our basic model, the information structure is the same as in Kwerel's model, but we add a demand for permits from citizens. Due to citizens' demand, Kwerel's mechanism is no longer incentive compatible. We then consider a modification of his mechanism, which we call the *minimum-price mechanism*. The government uses the same rule as Kwerel's mechanism to select the endowment of permits. But rather than giving a subsidy for pollution reduction, the government enforces a minimum price. The minimum-price mechanism is strictly incentive compatible.

We also consider an extension to the basic model in which damages from pollution are no longer common knowledge. Rather, the government has probabilistic beliefs about the damages from pollution and firms have probabilistic beliefs about the citizens' demand. Under general conditions on these beliefs, the minimum-price mechanism is weakly incentive compatible. If we add an extra condition relating the firms' beliefs to the government's beliefs, however, the minimum-price mechanism becomes strictly incentive compatible.

2 The Basic Model and Mechanisms

Following Kwerel's model and notation, let X be total emissions of pollution. Damage as a function of emissions is denoted by $D(X)$ and is common knowledge to citizens, the government, and firms. The first derivative D' and the second derivative D'' are both positive.

The government selects the endowment of permits L and other parameters as described

[1] Boyd and Conley (1997) and Conley and Smith (2005) consider markets in which citizens are charged personalized prices. Markets in which citizens are charged a common price are analyzed by Guha (1996), Ahlheim and Schneider (2002), Shrestha (1998), Smith and Yates (2003), and Malueg and Yates (2006). Israel (2005) documents the degree to which citizens actually retire permits in the EPA's acid rain program.

below. Following Kwerel, we assume that the government does *not* grandfather any permits to the firms (or the citizens for that matter) and the permit market is competitive. One interpretation of this structure is that the government auctions all permits and the rules of the auction are constructed such that it yields the competitive price.[2] Let p be the price of permits.

There are many polluting firms. Each firm has an abatement cost function which is private information. In the permit market each firm selects permit holdings such that it's individual marginal abatement cost is equal to the price of permits. It follows that the marginal abatement costs are equal across all firms. Without loss of generality, then, we need only consider the aggregate abatement cost function[3], which we denote by $C(X)$. The first derivative C' is negative and second derivative C'' is positive. The efficient level of pollution is the value X^* that satisfies $D'(X^*) = -C'(X^*)$.

Our basic model is constructed by adding a demand for permits from citizens to Kwerel's model. Let R be the quantity of permit purchases by citizens. At first we assume that demand fully captures damages, later we allow free-riding by citizens. Given L and p, the citizens solve

$$\min_{R} \; D(L - R) + pR$$
$$\text{such that } R \geq 0.$$

The market price determines whether the constraint is binding. If $p \geq D'(L)$, then citizens are "priced out" of the market and their demand is zero. The marginal damage at the endowment of permits is less than the price and so permits are too expensive to retire. If $p < D'(L)$, then citizens' demand is determined by the first-order condition

$$p = D'(L - R). \tag{1}$$

Citizens buy permits until the marginal damage at the level of pollution $L - R$ is equal to the price.

In a mechanism, the government asks the firms to report their abatement cost functions. Based on their responses, the government determines the structure of the pollution permit market in which firms and citizens purchase permits. The firms know how the government is going to use the information that the firms report. Let the reported aggregate abatement cost function be denoted by $\hat{C}(X)$.

We now present the two mechanisms and give a brief intuitive discussion of their properties. Formal propositions are given below.

Kwerel mechanism. *The government issues an endowment of permits L. It also pays a subsidy e per permit held in excess of emissions. The government selects the parameters L and e such that $D'(L) = -\hat{C}'(L) = e$.*

The government selects the permit endowment such that marginal damage is equal to reported marginal abatement cost. The subsidy is equal to the value of marginal damage

[2] In the minimum-price mechanism, the auction must yield the competitive price or the minimum price, whichever is greater.

[3] Let firm j have emissions x_j and abatement cost $c_j(x_j)$. The aggregate abatement cost is defined by $C(X) = \min \sum c_j(x_j)$ such that $\sum x_j = X$.

at this endowment. Suppose for the moment, as Kwerel implicitly does, that there is no demand from citizens. If firms understate their abatement costs, then the government issues a small endowment of permits, and thus the market price of permits will be high. If firms overstate their abatement costs, then the government issues a large endowment of permits, but the market price of permits will be high because of the subsidy. Firms can obtain the lowest price by telling the truth. This result does not hold, however, when we account for demand from citizens. Loosely speaking, the subsidy induces citizens to purchase too many permits. Because of this, the firms understate their abatement costs.

To be incentive compatible, a mechanism must keep the price of permits high when firms overstate their costs. Kwerel's mechanism uses a subsidy, but this entices citizens to purchase too many permits. The trick is to keep the price high without inducing citizens into the market. The government can do this by enforcing a minimum price in the permit market.

Minimum-price mechanism. *The government issues an endowment of permits L. It also enforces a minimum price $\bar{p}$ in the permit market. The government selects the parameters L and $\bar{p}$ such that $D'(L) = -\hat{C}'(L) = \bar{p}$*

The endowment of permits is set as in the Kwerel Mechanism and the minimum price is equal to marginal damage at the endowment of permits. Under the minimum-price mechanism, firms tell the truth.

3 No Citizen Demand

In this section we briefly review the details of Kwerel's result under the assumption that there is no demand from citizens. Rather than directly stating Kwerel's theorem, we state a proposition based on the key step in the proof of his theorem. This facilitates comparisons with the minimum-price mechanism. Let $p(L)$ be the equilibrium price of permits as a function of the permit endowment.

Proposition 1. *Suppose that there is no demand from citizens, and the government uses the Kwerel mechanism. Then $p(L)$ attains a strict global minimum at X^*.*

With this proposition in hand, we are only a corollary or two away from Kwerel's theorem. Because each firm's total cost (abatement cost plus permit expenditures) is increasing in p, it follows that each firm's total costs are minimized when the government picks $L = X^*$. If every other firm reports their true abatement costs, then the best strategy for a given firm is to report their true abatement costs. As stated by Kwerel, telling the truth is a Nash equilibrium.

4 Citizen Demand

In this section, we present formal results for the two mechanisms under the assumption that citizens do have a demand for permits.

First consider the Kwerel mechanism. Because citizens do not generate emissions, they obtain the subsidy for every permit purchased. So their effective price for permits is $p - e$.

(The government could try to prevent citizens from obtaining the subsidy, but such efforts are costly.) If

$$-C'(L) \geq D'(L) + e. \tag{2}$$

then the permit endowment is such that, at the endowment, the value of permits to firms is greater than value of permits to citizens. Thus citizens are priced out of market and $p = -C'(L)$. On the other hand, if, at the endowment, the value of permits to citizens is greater than the value of permits to firms then both firms and citizens purchase permits. The equilibrium quantity of pollution is found at the intersection of $D'(X) + e$ and $-C'(X)$. So the market price and equilibrium quantity of pollution are determined by

$$D'(X) + e - C'(X) = p. \tag{3}$$

In equilibrium, citizens retire $R = L - X$ permits.

The following proposition delineates the effect of citizens' demand on the Kwerel mechanism. (All proofs are in the Appendix.)

Proposition 2. *Suppose that citizens have a demand for permits, and the government uses the Kwerel mechanism. Then there exists a L_k (with $L_k < X^*$), such that $p(L)$ attains a strict global minimum at L_k.*

Because $p(L)$ attains a strict global minimum at a value less than the efficient level, firms have an incentive to understate their costs. The problem is the subsidy induces citizens to purchase more permits than they otherwise would. This drives the price up, which hurts firms. The best strategy for firms is to understate costs so that citizens are just priced out of the market.

Next we consider the minimum-price mechanism. The citizens are priced out of the market in this mechanism, as the market price is greater than or equal to the minimum price, which in turn is equal to marginal damage at the permit endowment. If firms understate, the market price is high. If firms overstate, the market price is also high because of the minimum price. Firms obtain the lowest price by telling the truth.

Proposition 3. *Suppose that citizens have a demand for permits, and the government uses the minimum-price mechanism. Then $p(L)$ attains a strict global minimum at X^*.*

5 Uncertain Damages

In this section, we relax the assumption that the damage function is common knowledge by defining probabilistic beliefs for the firms and the government. We also allow for free-riding by citizens.

Firms care about damages only insofar as these damages lead to a demand for permits by citizens. So the firms' beliefs should be defined with respect to this demand, or more primitively, the function that generates this demand. To keep the analysis tractable, we assume that the all firms have identical beliefs. Accordingly, let the firms' beliefs be summarized by the function $E(X, \varepsilon)$, where ε is a random variable. In other words, firms believe the citizens' demand for permits is determined by

$$\min_R \; E(L-R,\varepsilon)+pR$$
$$\text{such that } R \geq 0.$$

The function E obviously accounts for uncertainty about the severity of damages from pollution. But it also accounts for uncertainty about the degree of free-riding by citizens, because the degree of free-riding influences the citizens' demand for permits. Because of free-riding, then, *ex. post* actual damages are not necessarily equal to E. As usual, we assume E has positive first and second derivatives with respect to X.

For the government, it is sufficient to specify an expected damage function $K(X)$ (with $K' > 0$ and $K'' > 0$). The government announces this function to the firms and citizens. Even in the absence of free-riding, the government may have different beliefs about damages than the firms. So we do not require the expected value of $E(X,\varepsilon)$ to be equal to $K(X)$.

The parameters L and $\bar{p}$ in the minimum-price mechanism are determined such that $K'(L) = -\hat{C}'(L) = \bar{p}$. The analysis depends on the relationship between the firms' aggregate marginal abatement cost, the government's expected marginal damage, and the citizens' function E. Figure 1 illustrates these functions for a particular realization ϵ of ε. It also illustrates two critical price and pollution pairs. We interpret p_o as the market price that would prevail in the absence of a price minimum, provided L is sufficiently large. It is defined as $p_o = -C'(X_o)$, where X_o solves $-C'(X_o) = E'(X_o,\epsilon)$. We interpret $\tilde{p}$ as the government's expected price for permits in the absence of citizen participation, provided firms tell the truth. It is defined as $\tilde{p} = -C'(\tilde{X})$, where $\tilde{X}$ solves $-C'(\tilde{X}) = K'(\tilde{X})$.

The next proposition delineates the properties of the minimum-price mechanism with uncertain damages.

Proposition 4. *Suppose that citizens have a demand for permits, the government uses the minimum-price mechanism, and the damages are uncertain to the government and firms. Then for any ϵ such that $p_o < \tilde{p}$, the price function $p(L)$ attains a strict global minimum at $\tilde{X}$. For any ϵ such that $p_0 \geq \tilde{p}$, the price function $p(L)$ attains a global minimum at $\tilde{X}$.*

Proposition 4 is stated with respect to a single realization ϵ. We must consider the entire distribution of the random variable ε to determine the expected total costs for firms. But it follows directly from Proposition 4 that $L = \tilde{X}$ is a minimum of expected total costs for each of the firms.[4] Thus the minimum-price mechanism is weakly incentive compatible.

If we impose an extra condition relating the firms' beliefs to the government's beliefs, then the minimum-price mechanism is strictly incentive compatible. Suppose there exists a realization ϵ of ε such that $p_o < \tilde{p}$. Then for this ϵ, by Proposition 6, $L = \tilde{X}$ leads to a strict minimum of total costs. For any other ϵ, by Proposition 6, $L = \tilde{X}$ leads to at least a minimum of total costs. Thus $L = \tilde{X}$ leads to a strict minimum of expected total costs. To understand why the extra condition is required, suppose for the moment that relationship between $E'(X,\epsilon)$ and $K'(X)$ shown in Figure 1 holds for every ϵ, so that the extra condition

[4] The market price is, in general, a function of L and ϵ. Firm $j's$ total costs are given by $T_j(p(L,\epsilon)) = \min_{x_j} c_j(x_j) + p(L,\epsilon)x_j$. Because T_j is increasing in p, Proposition 4 implies that $T_j(p(\tilde{X},\epsilon)) \leq T_j(p(L,\epsilon))$ for each ϵ and each L.

is *not satisfied*. Then an endowment of $\tilde{X}$ leads to a minimum of total expected costs, but so does any value slightly greater (but not too great so that the minimum-price constraint starts to bind) and so does any value slightly smaller (but not too small such that citizens are priced out of the market.)

6 Conclusion

When damages are common knowledge, the minimum-price mechanism not only induces firms to tell the truth, but leads to the efficient amount of pollution as well. When damages are uncertain, the mechanism does not usually lead to efficiency. This raises the interesting possibility that the government could improve welfare by understating or overstating expected marginal damages $K(X)$. To determine the welfare maximizing function $K(X)$, one must specify the government's beliefs about marginal abatement costs, the damage from pollution, the free-riding of citizens, as well as specify the government's beliefs about the beliefs of the firms about the demand for permits. We leave such an analysis to further work.

7 Appendix

Proof of Proposition 2. Equation (2) gives the condition for citizens to be priced out of the market. Now in Kwerel's mechanism, $e = D'(L)$. So (2) becomes

$$-C'(L) \geq 2D'(L)$$

Let L_k be the value of L that satisfies this equation with equality. For $L = L_k$ we have $p = -C'(L_k)$. We also know that $L_k < X^*$. (Because $-C'(L_k) = 2D'(L_k)$ it follows that $-C'(L_k) > D'(L_k)$. Then $L_k < X^*$ follows from the definition of X^* and the fact that $D'' > 0$ and $C'' > 0$.)

For $L < L_k$, the fact that $D'' > 0$ implies $e = D'(L) < D'(L_K)$. Likewise, the fact that $C'' > 0$ implies that $-C'(L) > -C'(L_k)$. So for $L < L_k$ we have

$$D'(L) + e < 2D'(L_k) = -C'(L_k) < -C'(L).$$

It follows that citizens are priced out of the market and we have $p = -C'(L) > -C'(L_k)$.

Now for $L > L_k$ the fact that $D'' > 0$ implies that $e = D'(L) > D'(L_k)$. Likewise, fact that $C'' > 0$ implies that $-C'(L) < -C'(L_k)$. So for $L > L_k$ we have

$$D'(L) + e > 2D'(L_k) = -C'(L_k) > -C'(L).$$

It follows that citizens and firms purchase permits and the equilibrium market price is determined by equation (3). With $e = D'(L)$ equation (3) becomes

$$D'(X) + D'(L) = -C'(X).$$

Re-arranging yields

$$-C'(X) - D'(X) = D'(L). \tag{4}$$

From the definition of L_k we have

$$-C'(L_k) - D'(L_k) = D'(L_k). \tag{5}$$

Because $D'(L) > D'(L_k)$, it follows from (4) and (5), as well as $D'' > 0$ and $C'' > 0$, that $X < L_k$. Now, from (3), we have $p = -C'(X)$ and since $C'' > 0$ we have $p = -C'(X) > -C'(L_k)$.

In summary, for $L < L_k$, we have $p > -C'(L_k)$. For $L > L_k$, we have $p > -C'(L_k)$. And for $L = L_k$ we have $p = -C'(L_k)$. Thus $p(L)$ attains a strict global minimum at L_k, and as noted above, $L_k < X^*$. □

Proof of Proposition 3. Citizens are always priced out of the market. Let L_m be the solution to $D'(L) = -C'(L)$. By definition of efficiency, $L_m = X^*$. For $L = L_m$, we have $p = \bar{p} = D'(X^*) = -C'(X^*)$.

For $L < L_m$, we have $\bar{p} = D'(L) < -C'(L)$. So the equilibrium price has $p = -C'(L)$ and because $C'' > 0$, we have $C'(L) > -C'(X^*)$. Thus $p > -C'(X^*)$.

For $L > L_m$, we have $\bar{p} = D'(L) > C'(L)$. So the equilibrium price is equal to the minimum price. Because $D'' > 0$ we have $\bar{p} = D'(L) > D'(X^*) = -C'(X^*)$. So the equilibrium price is greater than $C'(X^*)$.

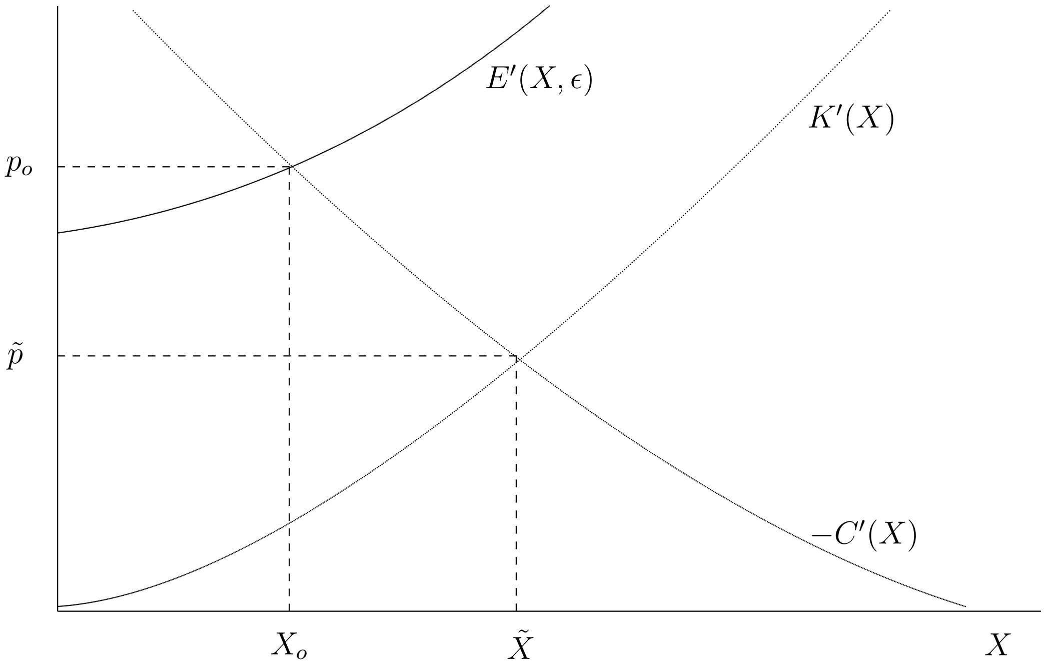
Thus $p(L)$ attains a strict global minimum at L_m. □

Proof of Proposition 4

Suppose first that for some realization ϵ, it is the case that $p_o < \tilde{p}$. Then because $C'' > 0$ we have $X_o > \tilde{X}$. We show that $p(L)$ has a strict global minimum at $\tilde{X}$. First, consider the case $L < \tilde{X}$. Because $C'' > 0$ we have $-C'(L) > -C'(\tilde{X}) = \tilde{p}$. Because $E'' > 0$ we have $\tilde{p} > p_o = E'(X_o, \epsilon) > E'(L, \epsilon)$. Thus it follows that $-C'(L) > E'(L, \epsilon)$ and citizens are priced out of the market. By the definition of $\tilde{X}$, we have $-C'(L) > K'(L)$ and so the minimum price constraint in not binding. So the equilibrium price satisfies $p = -C'(L) > \tilde{p}$. Second, consider the case $L = \tilde{X}$. Following similar arguments to the previous case, citizens are priced out of the market and the equilibrium price is $\tilde{p}$. Third, consider the case $L > \tilde{X}$. By definition of the minimum price, we have $p \geq \bar{p} = K'(L)$. Because $K'' > 0$, we have $K'(L) > \tilde{p}$. Thus $p > \tilde{p}$. We conclude that if $p_o < \tilde{p}$, then $p(L)$ has a strict global minimum at $L = \tilde{X}$.

On the other hand, if $p_o \geq \tilde{p}$, then we have $X_o \leq \tilde{X}$. We show that $p(L)$ has a global minimum, but not necessarily a strict global minimum, at $\tilde{X}$. First consider the case $L \leq X_o$. Because $C'' > 0$ and $E'' > 0$, we have $-C'(L) > -C'(X_o) = E'(X_o, \epsilon) > E'(L, \epsilon)$. Thus citizens are priced out of the market. Likewise, because $L < \tilde{X}$ we have $-C'(L) > K'(L)$, so the minimum price constraint is not binding. So the equilibrium price is given by $p = -C'(L) \geq p_o$. Second, consider the case $L > X_o$. Because $E'' > 0$, we have $E'(L, \epsilon) > p_o$. So citizens will participate in the market for any price at or below p_o, and hence the equilibrium price cannot be below p_o. It will only be greater than p_o if the minimum price constraint is strictly binding. This constraint cannot be strictly binding, however, at $L = \tilde{X}$, because $p_o \geq \tilde{p}$ and $\bar{p} = K'(\tilde{X}) = \tilde{p}$. So for $L = \tilde{X}$ the equilibrium price is p_o. We conclude that if $p_o \geq \tilde{p}$ then $p(L)$ has a global minimum at $\tilde{X}$.

Figure 1: Uncertain Damages



References

1. Ahlheim, M. and F. Schneider (2002) "Allowing for household preferences in emission trading" *Environmental and Resource Economics* **21**, 317–342.

2. Boyd, J. and J. Conley (1997) "Fundamental nonconvexities in Arrovian markets and a Coasian solution to the problem of externalities" *Journal of Economic Theory* **72**, 388–407.

3. Conley, J. and S. Smith (2005) "Coasian equilibrium" *Journal of Mathematical Economics* **41**, 687-704.

4. Dasgupta, P., Hammond, P., and E. Maskin (1980) "On imperfect information and optimal pollution control" *Review of Economic Studies* **47**, 857-860.

5. Goodstein, E. (2002) *Economics and the Environment*, John Wiley: New York.

6. Guha, A. (1996) "Internationalizing the role of domestic pollution permit markets" *Eastern Economic Journal* **22**, 449-456.

7. Israel, D. (2005) "Reducing acid rain, one allowance at a time" Indiana State University.

8. Kolstad, C. (2000) *Environmental Economics*, Oxford University Press: New York.

9. Kwerel, E. (1977) "To tell the truth: imperfect information and optimal pollution control" *Review of Economic Studies* **44**, 595-601.

10. Lewis, T. and D. Sappington (1995) "Using markets to allocate pollution permits and other scarce resource rights under limited information" *Journal of Public Economics* **57**, 431-455.

11. Malueg, D. and A. Yates (2006) "Citizen participation in pollution permit markets" *Journal of Environmental Economics and Management* **51**, 205-217.

12. Shrestha, R. (1998) "Uncertainty and the choice of policy instruments: a note on Baumol and Oates propositions" *Environmental and Resource Economics* **12**, 497–505.

13. Smith, S. and A. Yates (2003) "Optimal pollution permit endowments in markets with endogenous emissions" *Journal of Environmental Economics and Management* **46**, 425–445.