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Marketable Pollution Permits with Incomplete Enforcement

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Pollution

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Introduction

The purpose of this paper is to examine the effects of incomplete enforcement on a pollution control system relying on transferable discharge permits (TDPs). We will investigate how both pollution quantities and the compliance status of regulated firms in a permit system compare with a system of uniform standards in situations where regulators lack sufficient resources to bring about strict adherence to legal pollution limits. Although the efficiency gains of permits over standards tends to make compliance more attractive to firms, other factors unique to a TDP system can in some circumstances increase overall pollution and the number of firms which exceed their legal property rights. The penalty structure faced by regulated firms should be considered in determining how a TDP system will work when implemented.

Economists have long advocated the uses of market mechanisms as efficient means of implementing pollution control strategies. The idea of issuing property rights for effluents, which can then be traded between firms, has been the alternative to Pigouvian taxes which has drawn the most analysis and support in the economic literature since it was first proposed (Dales 1968). It is a well-established result that once property rights are defined, firms will trade among themselves so as to equalize their marginal costs of pollution abatement. In doing so, they will limit themselves to the amount of pollution allowed by the property rights at the least possible total cost. There have already been several experiments with limited forms of emissions trading schemes (Hahn 1989), and schemes with even wider markets are being proposed in the Bush Administration's legislation on acid rain and in the South Coast Air Basin's Air Quality Management Plan.

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It has become increasingly clear over the last decade that enforcing pollution control regulations is a major weakness of U.S. environmental policy (Russell, et.al. 1986, DiMento 1986). Setting maximum effluent limits and having regulated firms achieve these limits are two very different propositions. The seriousness of this problem can be demonstrated through a few statistics. In the four-year period beginning in 1977 there were 2,366 EPA enforcement actions for firms violating their National Pollution Discharge Elimination System permits and 424 notices of violation of the Toxic Substances Control Act. These were only a fraction of actual violations (DiMento). In 1983, 60% of facilities with the responsibility to monitor their effects on groundwater quality were out of compliance (DiMento). An Environmental Protection Agency/ Council on Environmental Quality study in the late 1970's found 65% of its sample out of compliance with air pollution emissions limits some time during the study period (Russell 1990). These situations may well represent worst-case compliance among the wide range of environmental regulations; they are offered only to emphasize that incomplete enforcement is an important factor in U.S. environmental policy. A priori, there is no reason to believe that firms will comply with their property rights under a TDP system any more than under standards. Hahn (1988) notes that improved enforcement is essential to the successful use of marketable property rights systems, and Tietenberg (1986) discusses problems of enforcement in his study of the limited property rights strategies employed by EPA in the 1980's.

A comparison between a TDP system and uniform standards is important to the evaluation of permit markets as an instrument of environmental regulation. TDP systems will most likely be implemented as a modification to existing quantity-based standards or command-and-control systems. The property of exact control over quantities is what makes property-rights-based systems politically and philosophically acceptable to many environmentally concerned citizens and policy makers. Marketable permits have been espoused as an attractive alternative to price instruments (taxes or other pollution charges) largely because they are an exact quantity instrument. In theory they allow the same control over pollution levels as do standards while sharing the attractive efficiency properties of taxes. It is therefore natural to ask whether the most attractive quality of these systems relative to standards- the same amount of pollution at a lower cost - persists under regimes of incomplete enforcement as well. The performance of TDP systems in controlling the quantity of pollution and influencing the compliance status of firms is therefore highly relevant to their implementation and acceptance.

Incomplete Enforcement

Most economic literature on pollution control has implicitly assumed that firms would dutifully follow whatever policy was set by the regulatory authority (Russell, et.al.). The recent literature on incomplete enforcement has completely abandoned this approach and assumed that firms only limit their pollution when it is in their interest to do so. The firm is modelled as facing a penalty when it exceeds some standard <u>and</u> the regulator is able to discover and verify the violation. If the regulator has insufficient resources to constantly monitor the entire regulated population, then the probability of detecting a violation is less than one. Russell, et. al. present convincing evidence that this is in fact the case. Their research, and that of Harrington (1989), focuses on the probability of monitoring and its effect on firm behavior under standards in a variety of contexts. In this paper we will be interested only in the firm's perceived penalty - the product of its probability of monitoring and its penalty if caught above what is allowed. We will ignore any stochasticity in monitoring accuracy and polluting behavior and will assume that the regulator's monitoring readings are always correct and the firm has perfect control over its discharges.

Viscusi and Zeckhauser (1979) examined a fixed penalty for failure to comply with a standard; the marginal incentive not to pollute more once the standard has been breached is zero. The use of a fixed penalty is troublesome; we do not frequently observe total disregard for pollution standards where there is any regulatory effort. Harford (1978) modelled penalty functions which could exhibit declining, constant, or increasing penalties for additional pollution above the standard. Jones (1989) extended this model and emphasized the importance of the shape of the marginal penalty curve in the firm's reaction to changing levels of stringency in the standard. She points out that even if the penalty imposed by the regulator is fixed, it is plausible that the probability of detection must increase at least marginally with the size of the violation.

Variables and Assumptions

We will employ a one-period model where a group of profit-maximizing firms face penalties for exceeding their allowed pollution levels. In order to investigate how a permit system might work as opposed to a particular pollution standard, we will assume that each firm's initial allocation of permits is equal to its non-transferable property right under standards. Our comparison will focus on the amount of pollution generated and the number of firms which violate their allowed pollution levels. We will examine three cases: constant, increasing, and decreasing marginal penalties. All firms' identical expected penalties per unit of violation are given by a function f(v) which is continuous in the positive domain and zero when $v \leq 0$; this function is the same for violations occuring under either regulatory regime. We will model all firms in the regulated population as facing the same expected penalty as a function of the size of their violation. This violation is calculated in relation to the firm's "property right" to pollute. Under uniform standards, each firm's property right is defined as the standard; under a permit system, the property right is determined by transactions in the permit market.

The n firms in this model are differentiated by their costs of pollution abatement, written $c^i(x^i)$ as a function of the quantity of effluent. Abatement here represents the firm's least-cost combination of treatment equipment, process changes, and production cutbacks; it reflects the minimum subtraction from unregulated profits for a given effluent level. It is assumed to be a continuous decreasing function of the amount of pollution. The usual assumption that the marginal cost of abatement increases as pollution quantities get smaller is made as well: $c_{xx} < 0$. The uniform standard facing each firm is $\bar{s}$; this is also each firm's initial property right under a TDP system. Permit holdings after market transactions are given for each firm by $\bar{x}^i$. A firm's violation under standards is given by $v_s = x_s - \bar{s}$ and the violation under the permit system is written $v_p = x_p - \bar{x}$. In order to ensure that abatement has a positive cost over some range and that if any firm has no property rights at all it will still find it in its interest to emit some effluent, it is assumed that $c_x(0) < 0$ and $-c_x(0) > f_v(0)$ for all firms. For all cases analyzed below, we assume that under standards there are j firms for which $v_s = 0$ and n - j firms for which $v_s > 0$; $0 < j < n$. This assumption ensures that we are examining a situation where the regulator has sufficient resources and authority to achieve compliance by some, but not all, firms in the regulated population under standards. This situation fits the stylized facts presented in the literature (Russell, et. al. 1986, Harrington 1989); it is unlikely that all firms will be out of compliance with any given regulation. We denote the equilibrium permit price by p and define $\hat{x}^i$ as the level of effluent where $c_x^i(x_p) = f_v(0)$: the point for each firm where the cost of abatement is uniquely equal to the marginal expected penalty for the first unit of violation.

The Model

Under standards, firms minimize the sum of abatement costs and penalties by choosing an effluent level:

$$\text{(1)} \quad \min_{x_s^i} \; c^i(x_s) + f(v_s) \; \textit{subject to} \; x_s^i \geq \bar{s}$$

The Kuhn-Tucker conditions for a minimum for each firm are:

$$\text{(2)} \quad \frac{\partial \mathcal{L}}{\partial x_s} = \frac{\partial c^i}{\partial x_s^i} + \frac{\partial f}{\partial v_s} \cdot \frac{\partial v_p}{\partial x_s^i} - \mu \geq 0; \quad \frac{\partial \mathcal{L}}{\partial x_s} \cdot x_s = 0 \qquad \text{(3)} \quad \frac{\partial \mathcal{L}}{\partial \mu} = x_s - \bar{s} \geq 0; \quad \frac{\partial \mathcal{L}}{\partial \mu} \cdot \mu = 0$$

for the firms which comply with the standard, $\mu = 0$ and $x_s = \bar{s}$. For the firms which do not, it is cheaper to produce at a positive level of violation at $-c_x = f_v$. These non-complying firms produce until their marginal abatement cost is equal to the marginal penalty. The total effluent can be written as $n \cdot \bar{s} + \sum_{j+1}^{n} (x_s^i - \bar{s})$.

The firm's objective function under a permit system, where its initial property right is equal to $\bar{s}$, is

$$\text{(4)} \quad \min_{x_p^i, \bar{x}} \; c^i(x_p^i) + f(v_p) + p \cdot (\bar{x} - \bar{s}) \textit{ subject to } \bar{x} > 0 \textit{ and } v_p \geq 0$$

and the Kuhn-Tucker conditions for a minimum a(with μ_1 as the multiplier on the first constraint and μ_2 on the second) are

$$\text{(5)} \quad \frac{\partial \mathcal{L}}{\partial x_p} = \frac{\partial c}{\partial x_p} + \frac{\partial f}{\partial v_p} \cdot \frac{\partial v_p}{\partial x_p} + \mu_2 \geq 0; \quad \frac{\partial \mathcal{L}}{\partial x_p} \cdot x_p = 0$$

$$\text{(6)} \quad \frac{\partial \mathcal{L}}{\partial \bar{x}} = -\frac{\partial f}{\partial v_p} \cdot \frac{\partial v_p}{\partial \bar{x}} + p + \mu_1 - \mu_2 \geq 0; \quad \frac{\partial \mathcal{L}}{\partial \bar{x}} \cdot \bar{x} = 0$$

$$\text{(7)} \quad \frac{\partial \mathcal{L}}{\partial \mu_1} = \bar{x} \geq 0; \quad \frac{\partial \mathcal{L}}{\partial \mu_1} \cdot \mu_1 = 0 \qquad \text{(8)} \quad \frac{\partial \mathcal{L}}{\partial \mu_2} = x_p - \bar{x} \geq 0; \quad \frac{\partial \mathcal{L}}{\partial \mu_2} \cdot \mu_2 = 0$$

These conditions can be interpreted to show the three possible least cost solutions for each firm:

(9) $\bar{x} > 0; \quad v_p > 0; \quad \frac{\partial f}{\partial v_p} = -\frac{\partial c^i}{\partial x_p} = p$ Firms choose levels of effluent and of violation such that they equate their marginal abatement costs, their marginal penalty for additional violations, and the price of permits. They hold a non-zero number of permits.

(10) $\bar{x} > 0; \quad v_p = 0; \quad \frac{\partial f}{\partial v_p} > -\frac{\partial c^i}{\partial x_p} = p$ Firms find it in their interest to comply with their property rights. They buy permits until their cost of abatement is equal to the permit price; this price must be less than the marginal penalty for the first unit of violation.

(11) $\bar{x} = 0; \quad v_p > 0; \quad \frac{\partial f}{\partial v_p} = -\frac{\partial c^i}{\partial x_p} < p$ Firms will sell all of their property rights and face

penalties on all of their effluent. They will pollute to the level where the marginal cost of abatement is equal to the marginal penalty.

Given a permit price, each firm will compare its total costs for each of the three solutions and choose the one which is lowest. Each firm's cost-minimizing strategy is characterized by a pair $\{x_p^{i*}(p), \bar{x}^*(p)\}$.

The market price of permits **p** is endogenous to this system. The supply of permits is fixed at $n \cdot \bar{s}$; the demand for permits at any price is the summation of the individual firms' optimal $\bar{x}^*(p)$. Thus total demand for permits $\bar{X}$ as a function of price is $\bar{X}(p) = \sum_1^n \bar{x}^{i*}(p)$; since $x^*(p)$ is non-increasing in p for all firms, the market demand $\bar{X}(p)$ is also non-increasing in p. The equilibrium price p^* occurs when the market clears: $\bar{X}(p^*) = n \cdot \bar{s}$.

In all cases the financial burden on each firm can be no greater under the TDP system than under standards. This is because firms retain the option of choosing the same effluet level and retaining their full $\bar{s}$ of property rights. If they choose to alter either their permit holdings or their effluent level, it can only be because it decreases their overall costs of operation given the regulatory setting.

Constant Marginal Penalties

Let $f_x(v) = t$, a constant. Equations (2) and (3) now imply that either $x_s > \bar{s} \Rightarrow \mu = 0 \; and \; -\frac{\partial c^i}{\partial x_s} = t$ or $x_s = \bar{s} \Rightarrow \mu < 0 \; and \; -\frac{\partial c^i}{\partial x_s} < t$. Under standards, compliance will be determined by whether $c_x^i(\bar{s})$ is greater than or less than t. If it is greater, then the firm will find it cheaper to pay t per unit of violation until its marginal cost of abatement falls to t. If the marginal cost of abatement at the standard is less than the constant fine, then the firm will pollute exactly $\bar{s}$.

For the j firms which comply under standards, $\hat{x} < t$; for non-complying firms the inequality is reversed. Non-complying firms will continue to pollute until $c_x(x_p^i) = t$, with $\hat{x}^i > \bar{s}$. Total effluent will be equal to $j \cdot \bar{s} + \sum_{j+1}^{n} x_s^i = n \cdot \bar{s} + \sum_{j+1}^{n} (x_s^i - \bar{s})$.

Now let a marketable property right system be introduced with $\bar{s}$ permits distributed to each firm. When marginal penalties are constant, the penalty puts a ceiling on the permit price. No firm would ever pay more than t for a permit when it could produce the same effluent and pay t in penalties. This fact, together with the assumption that $x_p > 0$, means that we can eliminate $\bar{x} = 0$ as a possibility for a least-cost solution. This implies that all firms will choose a level of pollution where the marginal cost of abatement is equal to the equilibrium permit price. If that equilibrium price is less than t, then it must be true that $v_p = 0$ for all firms. If $p = t$, then all firms will pollute to $\hat{x}$.

Let us turn to the permit market to determine this equilibrium price. From $p = 0$ to $p = t$, permit demand decreases as price increases. Demand is horizontal at t: firms are indifferent between paying the penalty and buying permits. Whether $p = t$ or $p < t$ is determined by whether the actual quantity of existing property rights $n \cdot \bar{s}$ is less than or greater than the quantity demanded at a price just below t: $X(t-\varepsilon) = \sum_{1}^{n} \hat{x}^i \gtrless n \cdot \bar{s}$ We can rearrange this to give it some intuitive content. Firms which complied under standards will reduce their pollution from $\bar{s}$ to $\hat{x}$ at a permit price of t. The maximum net quantity demanded by each of the n-j firms which cheated under the standard is $\hat{x}^i - \bar{s}$. If the latter is greater than the former, demand will exist for all of the permits that complying firms make available at t and that will be the market-clearing price. If the n-j firms demand fewer permits at t than the j firms offer, the market will clear at a price less than t:

$$(12a)\ \sum_{1}^{j}(\bar{s}-\hat{x}^{i}) \leq \sum_{j+1}^{n}(\hat{x}^{i}-\bar{s}) \rightarrow p=t \qquad (12b)\ \sum_{1}^{j}(\bar{s}-\hat{x}^{i}) \geq \sum_{j+1}^{n}(\hat{x}^{i}-\bar{s}) \rightarrow p<t$$

If **(12a)** is the case, then the market price of permits is the same as the marginal tax rate and the number of firms complying will be the same or possibly less than under standards. The non-complying firms produce the same amount of effluent as before, but they will now hold permits for part of that effluent and so will violate the standard by less. Firms which initially complied under the standard will continue to comply, but will produce less effluent as they sell their rights for t and their marginal abatement cost rises to t. Overall pollution drops unambiguously by $\sum_{1}^{j}(\bar{s}-\hat{x}^{i})$.

If **(12b)** holds, then p < t. and all firms will now comply with their property rights. The total effluent is equal to the total property right $n\cdot\bar{s}$ In this case the marginal cost of abatement is equalized across all firms at a level less than t, and the permit system achieves the pollution level which a policy designed with perfect enforcement would have anticipated.

Thus with constant marginal penalties, the permit system performs better than the standard. Because the permit system lowers the marginal cost of abatement for high-cost firms without causing low-cost firms to cheat, there is less overall pollution and the same number or fewer firms which exceed their property right. This pollution level is achieved at a lower cost to firms.

Increasing Marginal Penalties

The penalty function perceived identically by all firms is now f(v); $f_{vv} > 0$. Let $f_v(0)$ be the marginal penalty for the first increment of effluent above each firm's property right. Then for the firms which comply under standards it will be true that $c_x^i(\bar{s}) \leq f_v(0)$. Non-complying firms will continue to pollute until $c_x^i(x_s) = f(v_s)$. Total effluent will be $n \cdot \bar{s} + \sum_{j+1}^{n} x_s^i - \bar{s}$. Now introduce a permit system as before. The equilibrium price of permits relative to the value $f_v(0)$ is now critical for determining compliance status. The firms which complied under permits will each sell $\bar{s} - \hat{x}^i$ at $p = f_v(0)$; the firms which cheated will demand $\hat{x}^i - \bar{s}$ at that price. Comparing net demand at $p = f_v(0)$ signals whether the equilibrium price will be lower or higher:

$$\text{(13a)} \sum_{1}^{j} (\bar{s} - \hat{x}^i) \geq \sum_{j+1}^{n} (\hat{x}^i - \bar{s}) \rightarrow p \leq f_v(0) \qquad \text{(13b)} \sum_{1}^{j} (\bar{s} - \hat{x}^i) < \sum_{j+1}^{n} (\hat{x}^i) \rightarrow p > f_v(0)$$

If $p < f_v(0)$, then **(9)** describes the equilibrium for all firms. Each firm complies with the number of permits it possesses and total effluent is $n \cdot \bar{s}$.

If the market-clearing price is greater than $f_v(0)$, then under the assumptions of this model all firms in the market will now be in violation of their legal property right to pollute. Although all firms will be cheating, there will be a tendency for the amount of pollution to fall. The firms that complied under standards will sell permits at least up to the point where $c_x^i = f_v(0)$; as long as there is no violation a decrease in their permit holdings will bring about a corresponding decrease in their effluent level ($\frac{dx_p}{d\bar{x}} = 1$). These firms will reduce their effluent by $\sum_{1}^{j} (\bar{s} - \hat{x}^i)$. The firms which buy these permits have positive levels of violation; for these firms $\frac{dx_p}{d\bar{x}} = \frac{f_{vv}}{f_{vv} + c_{xx}} \Rightarrow 0 < \frac{dx_p}{d\bar{x}} < 1$. Therefore the permits that change hands to bring the marginal abatement costs of the previously complying firms up to effluent. This is due to the reduced incentives to cheat for high-cost firms which results from the more efficient distribution of effluents through the permit system. As the price rises above $f_v(0)$, lower-cost firms which sell permits increase the size of their own violations as they decrease their effluent level; the high-cost firms that buy these permits do the opposite. Whether total pollution increases or decreases depends on the values of the second derivatives of the marginal penalty and marginal abatement cost functions. Firms with relatively flat marginal cost of abatement functions will change their effluent level more in response to a change in permit holdings than will firms with steeper functions. Other things being equal, if high cost firms have flatter abatement functions then pollution will increase; if they have steeper functions pollution will decrease. There is nothing definitive to be said about which is likely to be the case. We can, however, shed some light on the influence of the penalty function holding c_{xx} constant across firms. If the marginal penalty rises steeply from $f_v(0)$ and then flattens out ($f_{vvv}<0$), then pollution will decrease as low cost firms increase their violation sizes by less than high cost firms decrease theirs. If the marginal penalty rises slowly from $f_v(0)$ and then becomes steeper ($f_{vvv}>0$), then overall pollution will increase as high cost permit-buying firms decrease their violations by less than the permit-selling firms increase their violations. If the marginal penalty rises at a constant rate ($f_{vvv}=0$) then the changes in violations balance exactly and total effluent is left unchanged.

To summarize, the results for a permit system under increasing marginal penalties are more ambiguous than those for constant marginal penalties. If the market-clearing price of permits is less than the penalty for the initial unit of violation, then all firms comply and the quantity of effluent is less than that under standards. If the market-clearing price is above $f_v(0)$, however, then all firms in the market will now exceed their property rights. The sale of the permits which bring the firms complying under permits up to the point where violation becomes rational will unambiguously lessen overall pollution. As the price rises above $f_v(0)$, however, total pollution can either increase of decrease, depending on the nature of different firms' cost of abatement functions and the slope of the marginal penalty function. Total pollution can possibly increase as a result of a switch from standards to a permit system, although it seems reasonable that more often that not it would decrease.

Decreasing Marginal Penalties

Decreasng marginal penalties seems like a strange concept: why would enforcement policies make violations marginally less costly than smaller ones? At least one component of EPA penalty practices under the Clean Air Act, the Federal Water Pollution Control Act, and the Comprehensive Environmental Response, Compensation, and Liability Act calls for exactly this kin dof penalty, at least in theory. A major component of the fines faced by firms discovered in violation with these regulations is an amount equal to the economic gain of non-compliance; given an increasng marginal cost of abatement function this implies a declining marginal penalty.

The situation under standards with decreasing marginal penalties is the same as with the previous cases. The penalty function faced by all firms is characterized by $f_{vv}<0$; assume that $f_{vv}>-c_{xx}$ everywhere. For the firms which comply it will be true that $c_x^i(\bar{s}) \le f_v(0)$. Non-complying firms will continue to pollute until $c_x^i(x_s) = f(v_s)$. Total effluent will be $n \cdot \bar{s} + \sum_{j+1}^{n} x_s^i - \bar{s}$.

The permit price with declining marginal penalties is constrained to be less than $f_v(0)$; no firm would ever pay more than this because cheating would be cheaper. Unlike the previous two cases, (9) is no longer a possible solution for any firm. At the point where $p = f_v = -c_x$, the firm would reduce its costs by buying permits for the entire amount of its violation.

Compliance at $-c_x^i=p$ is one possibility for the firm's least cost strategy. The other is (11): $f_v(x_p)=-c_x(x_p)<p$. There is a unique permit price level for each firm below which the first option is less costly for the firm and above which the second is preferred. The firm's demand for permits is discontinuous at that point; below it the demand for permits is positive and above it demand is 0 (the firm sells its $\bar{s}$ property rights). The higher a firm's cost of abatement at any given pollution level, the lower the price at which that firm switches discontinuously from positive to zero permit demand. The market demand for permits $\bar{X}(p)$ is discontinuous at n points, and is horizontal at some point at or below $f_v(0)$.

The number of firms which comply decreases as the market-clearing price increases. A steeper marginal penalty function will increase the number of cheating firms. Holding other factors equal, more complying firms under standards having lower marginal costs of abatement at $\bar{s}$ will tend to decrease the number of cheating firms and overall pollution under permits. Thus total effluent could either increase or decrease with a declining marginal penalty. Firms which choose not to comply will pollute more than they did under standards; in addition, their property rights will be used by the complying firm that buys them. Even if more firms comply under permits than under standards, total pollution may still be higher.

Conclusion

We have found that when the enforcement of firms' property rights to pollute is incomplete, a marketable permit system can in some circumstances result in more pollution than a system of uniform standards. This is more likely to happen when the marginal penalty for violations is either rising at an increasing rate or decreasing rapidly. Under other very plausible circumstances, a permit system will produce less pollution. If the number of firms complying with the law is important in and of itself, a permit system can fare worse than standards under the assumptions employed in this paper even when it lowers overall pollution. While it is still true that in all circumstances a marketable permit system imposes lower costs on the regulated firms, the uncertain control over quantities and compliance status should cause analysts to think more about the nature of penalties faced by firms for pollution control violations and about the importance and enforcement in the design of permit systems.

There are two important considerations we have not examined here which would tend to make permits more attractive than standards in an environment of incomplete enforcement. One is that firms' transactions in the permit markets will provide a signal to regulators about their abatement costs. If firms cheat because they have high abatement costs, and if regulators could target their monitoring resources better if they knew which firms were more likely to cheat, then this signal could improve enforcement. Another consideration is that under many penalty structures permit prices increase as violations become more costly to the firm. Firms with low abatement costs who are net sellers of permits should therefore have less resistance to, or even find it in their interest to support, the devotion of more resources and authority to the enforcers of pollution control laws. More careful analysis of these phenomena is the subject of future research.

REFERENCES

Dales, J. H. *Pollution, Property and Prices*. Toronto: University of Toronto Press, 1968.

DiMento, Joseph F. *Environmental Law and American Business*. NY: Plenum Press, 1986.

Hahn, Robert W "Innovative Approaches for Reforming the Clean Air Act." *Natural Resources Journal* 28 (1988): 171-188.

Hahn, Robert W. "Economic Prescriptions for Environmental Problems: How the Patient Followed the Doctor's Orders." *Journal of Economic Perspectives* 3 (1989): 95-114.

Harford, Jon D. "Firm Behavior Under Imperfectly Enforceable Pollution Standards and Taxes." *Journal of Environmental Economics and Management* 5 (1978): 26-43.

Harrington, Winston, "Enforcement Leverage When Penalties are Restricted." *Journal of Public Economics* 37 (1988): 29-53.

Jones, Carol Adair, "Standard Setting with Incomplete Enforcement Revisited." *Journal of Policy Analysis and Management* 8 (1989): 72-87.

Russell, Clifford S., W. Harrington, and W.J. Vaughan *Enforcing Pollution Control Laws.* Baltimore, MD: Johns Hopkins University Press, 1986.

Russell, Clifford S. "Monitoring and Enforcement." in Public Policies for Environmental Protection, Paul R. Portney, editor. Washington, DC: Resources for the Future, 1990.

Tietenberg, T.H. *Emissions Trading*. Washington, DC: Resources for the Future, 1985.

Viscusi, W. Kip and R.J. Zeckhauser "Optimal Standards with Incomplete Enforcement." *Public Policy* 27 (1979): 437-456.