Enforcing Transferable Emission Permit Systems[1]

Stranlund, John and Kathy Dhanda. 1999. "Endogenous Monitoring and Enforcement of a Transferable Emissions Permit System", *Journal of Environmental Economics and Management* 38(3): 267-282.

Malik, Arun. 1990. "Markets for Pollution Control when Firms are Noncompliant", *Journal of Environmental Economics and Management* 18: 97-106.

1. A model of compliance in a transferable emission permits system

The Firm

Throughout we consider a risk neutral firm that operates in a competitive transferable permit system, along with a fixed number of heterogeneous other firms.[2] Each individual firm is a perfect competitor in the license market, so the license market generates a license price p.

Because we want to analyze intentional violations as opposed to violations that result from random acts of nature or equipment failures, let us assume that emissions are deterministic.[3]

The firm's abatement cost function is $c(e, \alpha)$, which is strictly decreasing and convex in the firm's emissions e [$c_e(e, \alpha) < 0$, $c_{ee}(e, \alpha) > 0$]. A firm is distinguished from others by the shift parameter α.[4]

Regulation and Enforcement

A total of L licenses are issued by a regulatory authority, each of which confers the legal right to release one unit of emissions. The total issuance of permits is fixed. Let l_0 denote the initial allocation of licenses to the firm, and let l be the number of licenses that the firm holds after trade.

When a firm is non-compliant, its emissions exceed the number of licenses it holds and the level of its violation is $e - l > 0$. The firm is compliant otherwise and $e - l = 0$.

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[1] The model and results presented in these notes are based largely on Stranlund and Dhanda (1999). The model is not unique in this literature, but there are differences. I will point out these differences as we proceed.

[2] Malik (1990), and Stranlund (2006) considers non-neutral attitudes toward risk.

[3] In contrast, Beavis and Walker (1983) assume that firms' emissions are stochastic.

[4] Firms' abatement costs can vary for many reasons, including differences in production and emissions control technologies, prices of inputs and outputs, and because of specific factors related to the industrial sector to which they belong.

Suppose that an enforcement authority chooses a monitoring strategy that may be firm specific. Let π denote the probability that the authority audits the firm. If a firm is audited and found to be non-compliant a given penalty $f(e-l)$ is imposed. As before, we assume that this penalty is zero for a zero emissions violation but the marginal penalty for a zero violation is greater than zero [$f(0) = 0$ and $f'(0) > 0$]. Further, for positive emissions violation the penalty is increasing at an increasing rate [$f''(e-l) > 0$]. Note that a non-compliant firm faces an expected penalty given by $\pi f(e-l)$.[5]

The Firms' Problem

Assume that a firm chooses its emissions, and permit demand to minimize compliance costs –abatement costs, receipts or expenditures from buying or selling permits, and the expected penalty- taking the enforcement strategy as given. Thus, the firm's problem is to choose emissions and licenses to solve

$$\begin{aligned} &min \quad c(e,\alpha) + p(l - l_0) + \pi f(e - l) \\ &s.t \quad e - l \geq 0. \end{aligned} \tag{1}$$

The Lagrange equation for (2.3) is $\theta = c(e,\alpha) + p(l - l_0) + \pi f(e - l) - \eta(e - l)$ and the Kuhn-Tucker conditions are:

$$\theta_e = c_e(e,\alpha) + \pi f'(e - l) - \eta = 0; \tag{2-a}$$

$$\theta_l = p - \pi f'(e - l) + \eta \leq 0,\ \theta_l \times (e - l) = 0; \tag{2-b}$$

$$\theta_\eta = e - l \geq 0,\ \eta \geq 0,\ \eta \times (e - l) = 0. \tag{2-c}$$

[5] Differences in modeling approaches in this literature often involve differences in the structure of the audit probability.[See for examples, Malik (1990), Keeler (1991), vanEgteren and Weber (1996), Mrozek (1995) and Mrozek (1997)]. In Malik's (1990) specification, the firm's subjective probability of being audited is a function of the level of emissions e, level of permits l, and a vector of unspecified exogenous audit parameters set by the enforcement agency δ; that is, $\pi = \pi(e, l; \delta)$. Both Keeler (1991) and vanEgteren and Weber (1995) assume that the audit probability depends only on the violation level. Mrozek (1995) suggests that the audit probability might depend on the initial allocation of licenses. I should note here that all of these are rather ad hoc specifications. Dependence of the audit probability on certain variables should come from a derivation of an enforcement authority's optimal monitoring strategy.

Given the structure of abatement costs and expected penalties, conditions (2a—c) are necessary and sufficient to determine the firm's optimal choices of emissions and licenses uniquely.

The model generates a number of interesting hypotheses about a firm's behavior in a transferable permit system:

(1) It is easy to show that a firm chooses its emissions up to the point where its marginal abatement cost equals the market permit price regardless of its compliance status; that is, $p = -c_e(e, \alpha)$.[6] Thus, the firm's choice of emissions is a function of the permit price and the shift parameter; that is, $e = e(p, \alpha)$. It is also easy to show that e is increasing in p.

(2) Two important implications stem from the result that a firm's choice of emissions is $e = e(p, \alpha)$. First, the firm's choice is independent of the enforcement strategy. Harford (1978) appears to have been the first to notice this result. Malik (1990) notes, however, that the equilibrium distribution of emissions will depend on the enforcement strategy because the enforcement strategy will affect the equilibrium permit price. The second implication of the firm's emissions choice is that, since all firms face the same license price, in an equilibrium, the firms' marginal abatement costs are all equal. This is the standard condition for minimizing aggregate abatement costs.[7] It also has important implications for an enforcer's ability to target its enforcement strategy at different firms.

(3) As for the firm's permit demand, when the firm is compliant the number of permits it demands is equal to its choice of emissions; that is $l(e, \alpha) = e(e, \alpha)$. However, given an optimal emissions-choice, when the firm is non-compliant it will demand permits up to the point where the price of a permit equals the marginal expected cost of not having that permit (and being in violation); that is, where $p = \pi f'(e(p, \alpha) - l)$.[8] [It is important to note that the marginal gain from being in violation is the license price, which, in a perfect competitive system is the same for all firms]. This marginal condition suggests that a non-compliant firm's license demand is a function of the license price, the shift

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[6] A proof follows. Suppose that the firm is non-compliant so that $e - l > 0$. Then, (2-b) and (2-c) require $\theta_l = \eta = 0$. Thus, (2-a) becomes $c_e(e, \alpha) + \pi f'(e - l) = 0$, and (2-b) becomes $p - \pi f'(e - l) = 0$. Taken together, (2-a) and (2-b) then imply $c_e(e, \alpha) + p = 0$. Now suppose that the firm is compliant. In this case its objective function reduces to $c_e(e, \alpha) + p(l - l_0)$, the minimization of which requires $c_e(e, \alpha) + p = 0$. I should note that this result does not necessarily hold under different specifications of the audit probability.

[7] Malik (1992) shows that equalizing marginal abatement costs will not minimize the sum of aggregate abatement costs and enforcement costs.

[8] To obtain this note from (2-b) and (2-c) that $e - l > 0$ implies $\eta = 0$ and $\theta_l = p - \pi f'(e - l) = 0$. Substituting the firm's emissions choice yields $p - \pi f'(e(p, \alpha) - l) = 0$, which implies $l = l(p, \alpha, \pi)$.

parameter, and the probability the firm will be audited; that is, $l = l(p, \alpha, \pi)$. It is easy to show that $l(p, \alpha, \pi)$ is decreasing in p and increasing in π.

(4) As for the firm's choice of violation, it can be shown that a firm is compliant if and only if

$$p \leq \pi f'(0)\,.^{9} \qquad (3)$$

That is, a firm is compliant if and only if the price per license that the firm faces is not greater than marginal expected penalty of a slight violation. This result is straightforward. Given $f''(e - l) > 0$ and (2.5), the price of the license is less than the marginal expected penalty for any non-zero violation; therefore, non-compliance is more costly for a firm than purchasing a sufficient number of licenses to be compliant. Note that the compliance decision does not depend on α, indicating that the decision to be compliant or not across firms does not depend on differences in the firms emissions-control costs. Stranlund and Dhanda (1999) extend this result further and show that the violations of non-compliant firms do not depend on differences in the firms' control costs.[10]

2. Implications for monitoring

The results of the compliance model suggest a number of important implications for monitoring firms in competitive transferable emissions permit systems.

(a) The compliance condition (3) suggests that an enforcer that wants to achieve complete compliance while conserving monitoring costs should audit each firm with probability $\pi = p/f'(0)$. Thus, given that penalties are applied uniformly, monitoring should also be uniform; that is, there is no need to target different types of firms.

(b) The fundamental lack of any firm specificity in the specification of the minimum audit probability is due to the equilibrating nature of frictionless and competitive transferable emissions permit systems. Since all firms choose emissions so that their marginal abatement costs are equal to the permit price, in any equilibrium, there are no

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[9] Versions of this result have been presented by a number of authors [Malik (1990), vanEgteren and Weber (1996), Stranlund and Dhanda (1999)], so I have decided not to present the proof here.

[10] To see this result, denote a non-compliant firm's violation as $v = e - l$. When the firm is non-compliant, (2-b) and (2-c) require $p - \pi f'(e - l) = 0$. Taking account of the firm's choice of emissions, $e\,(p, \alpha)$, and its choice of permits, $l(p, \alpha, \pi)$, we have $p - \pi f'(e\,(\alpha, p) - l\,(\alpha, p, \pi)) \equiv 0$. Differentiate this with respect to α to obtain $-\pi f'' \times (e_{\alpha} - l_{\alpha}) = 0$, which implies $e_{\alpha} - l_{\alpha} = 0$.

differences in marginal abatement costs among firms that the enforcement authority can exploit to target its monitoring effort.

(c) This suggests further that firm-specific information is not valuable in this context. This includes information that an enforcer is likely to have like a firm's initial allocation of permits l_0, as well as information that is private to firms (and hence, will be costly if not impossible to obtain) like characteristics that can be used to infer a firm's marginal control costs.[11] Since the latter pieces of information are not valuable, an enforcer faces no asymmetric information problems.

(d) These results do not hold in the context of emissions standards. As we have noticed before, when faced with an emission standard, a firm's marginal abatement costs indicate exactly its marginal benefit of non-compliance. Thus, given fixed penalties that are uniformly applied, a firm with high marginal abatement costs of achieving the emissions standard is more likely to be non-compliant. Thus, in this case, to minimize the monitoring costs of achieving full compliance, a regulator will want to target more of its monitoring effort at firms with higher marginal abatement costs. Clearly, information that can be used to get an indication of a firm's marginal abatement costs will be valuable to enforcers. However, since the relevant information will be privately held by the firms, an enforcer faces an asymmetric information problem.

(e) The same general results appear to hold in contexts in which complete compliance cannot be obtained. In the context of enforcing emissions standards, Garvie and Keeler (1994) show that a budget-constrained enforcer that wants to minimize aggregate noncompliance will target firms with high marginal abatement costs. Applying the same model except in the context of enforcing a transferable permit system, Stranlund and Dhanda (1999) show that targeting is neither necessary nor desirable.[12]

3. Implications for setting penalties

The compliance condition (3) also suggests that a regulator may want to tie marginal penalties to the equilibrium permit price [Stranlund and Chavez (2000) appear to be the first to suggest this strategy]. This recommendation corresponds well with suggestions to tie penalties to the economic gain to the offender from being non-compliant [Wasserman

[11] Contrary to Mrozek's (1995) claim, it is clear that the enforcer should not condition its enforcement strategy on a firm's initial allocation of permits. This follows from the fact that none of the firm's choices depend on the initial allocation, which is most easily seen by noting the absence of l_0 in any of the Khun-Tucker conditions (2-a) through (2-c).
[12] They show that this result depends on two earlier results: a firm's choice of emissions is independent of enforcement variables, and its choice of violation is independent of it marginal abatement costs. They point out that these are testable hypothesis that, at least in principle, can be subject to rigorous analysis to judge the validity of the non-targeting result.

(1992); for a discussion see Cohen (1998), section 3.5]. Note that since the equilibrium permit price is the marginal cost for a firm to achieve full compliance, it represents the marginal gain from being non-compliant. Therefore, using the gain-based criterion for setting penalties in a competitive transferable permit system implies that marginal penalties be tied to the equilibrium permit price. Furthermore, the information requirement is not severe. Under emissions standards, a gain-based penalty requires that the authority estimate an offender's marginal abatement costs. In a frictionless and competitive transferable emissions permit system the authority need only observe the equilibrium permit price.

Tying marginal penalties to the equilibrium permit price can also simplify an enforcer's monitoring strategy. Since effective enforcement of a competitive transferable permit system that is meant to achieve complete compliance requires $p \leq \pi f'(0)$, if the penalties are fixed the monitoring component must keep pace with fluctuations in the equilibrium permit price. This may be a difficult task for a regulator. However, choosing marginal penalties so that they vary directly with the equilibrium permit price will help stabilize the required audit strategy. For example, if the marginal penalty for an emissions violation is chosen to be $f'(e - l) = \phi p$, with $\phi \geq 1$ to satisfy $p \leq \pi f'(0)$, a constant audit probability $\pi = 1/\phi$ will guarantee complete compliance and is independent of fluctuations of the equilibrium permit price. This suggestion is discussed further in chapter 4 in the context of a competitive and frictionless market-based system with a self-reporting requirement.

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