NOTES ON ENFOCING ENVIRONMENTAL POLICIES[1]

1 Introduction

This chapter presents a brief review of the economic literature on enforcement of environmental policies. The first part of this chapter is a brief review of the literature on enforcing command-and-control environmental standards, focusing primarily on the issues in this literature that I feel are the most important for this dissertation research. The second part of this chapter is a somewhat longer review of the much smaller literature on enforcement of market-based environmental policies. Both of these sections include simple theoretical models that are used to motivate the discussions.

2. A Brief Review of the Literature on Enforcing Environmental Standards

The purpose of this section is to provide a brief review of the economic literature on enforcement of environmental regulations. To motivate the discussion, I consider a simple model of source compliance and its implications for enforcement design in the context of an emissions standard.

2.1 A simple model of compliance to environmental standards

Consider a risk-neutral firm that operates under a command-and-control environmental policy. Specifically, the firm faces an emissions standard s. The firm's emissions control function is $c(e)$, which is strictly decreasing and convex in the firm's

[1] These notes are adapted from Carlos Chávez. 2000. *Enforcing Market-Based Environmental Policies*. Ph. D. Dissertation. Department of Resource Economics, University of Massachusetts-Amherst.

emissions e [$c_e(e) < 0$ and $c_{ee}(e) > 0$].[2] An emissions violation occurs when the firm's emissions exceed the emissions standard; $(e - s) > 0$. The firm is compliant otherwise.

The firm faces a random probability of being audited π. An audit provides the regulator with perfect information about firm's compliance status. If the firm is audited and found in violation, a penalty $f(e - s)$ is imposed. The penalty is assumed to be zero for a zero violation, but the marginal penalty for zero violation is greater than zero [$f(0) = 0, f'(0) > 0$]. For a positive violation the penalty is increasing at an increasing rate [$f''(e - s) > 0$].

I assume that the emissions standard and the enforcement policy (audit probability and given penalty) are communicated to all firms. A firm chooses the level of emissions to minimize total expected compliance costs, which consists of its abatement costs plus its expected penalty. Thus, a firm's problem is to choose the level of emissions to solve

$$min\ c(e) + \pi f(e - s) \qquad (2.1)$$

$$s.t.\ e - s \geq 0.$$

Having specified the firm's problem, we can now turn to its choice of whether to be compliant or not: It compliant if and only if

$$- c_e(s) \leq \pi f'(0).^3 \qquad (2.2)$$

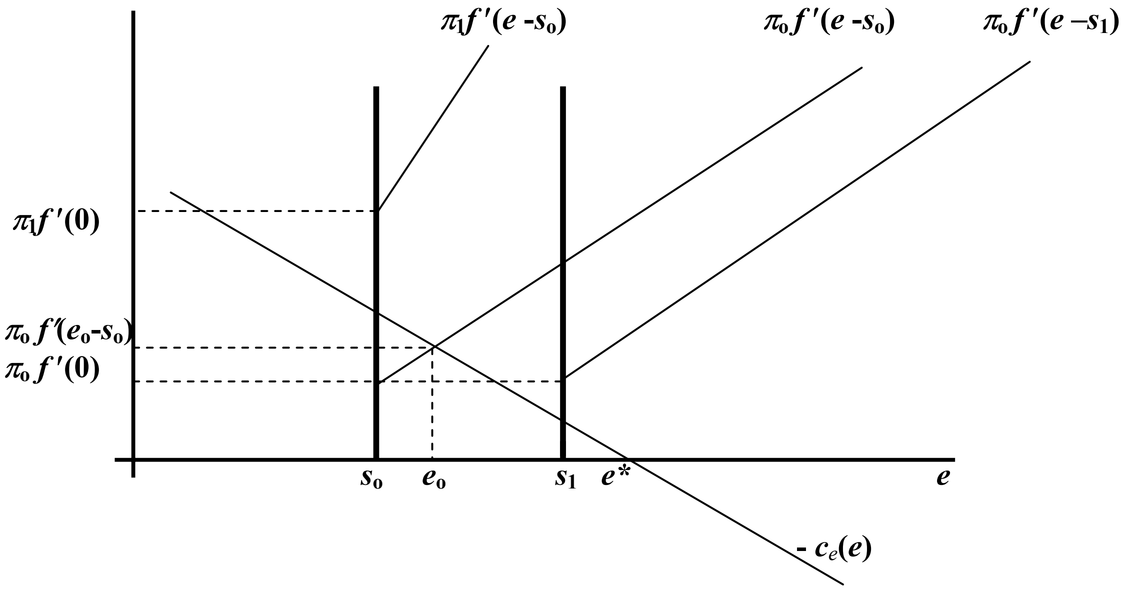
[2] The standard interpretation of $c(e)$ is as follows: Let e^* be the firm's unconstrained level of emissions and let $\pi(e^*)$ be the firm's maximal profit in this setting. The cost of holding its emissions to $e < e^*$ is $c(e) = \pi(e^*) - \pi(e)$. Montgomery (1972) showed that $c(e)$ is decreasing and convex when the firm is a price-taker in input and output markets, but since the formulation of $c(e)$ is quite general it will have these characteristics in many non-competitive settings as well.

[3] The Kuhn-Tucker condition for (2.1) is $c_e(e) + \pi f'(e - s) \geq 0$, if > 0, $e = s$. It follows that a firm is compliant if and only if $c_e(s) + \pi f'(0) \geq 0$ or, $-c_e(s) \leq \pi f'(0)$ as in (2.2).

Thus, a firm that is subject to an emissions standard will comply if and only if the marginal benefit from violating the regulation -its marginal abatement cost evaluated at the standard- is not greater than the expected marginal penalty of a slight violation.

A representation of the firm's compliance choice is illustrated in Figure 2.1. In the absence of regulation, Figure 2.1 suggests that a firm chooses its emissions to be e^*. When regulated by the imposition of an emissions standard, the firm faces an expected penalty of $\pi f(e - s)$, which is increasing in emissions at an increasing rate. Figure 2.1 shows different expected marginal penalty functions for which the shift parameters are the standard s and the auditing probability π. Consider now the firm's choice of emissions when it faces an emissions standard. Assuming initially that the regulatory policy is described by the pair (π_o, s_o), the firm optimally chooses emissions to be e_o so that $-c_e(e_o) = \pi_o f'(e_o - s_o)$. Therefore, the firm is in violation and the extent of the violation is $(e_o - s_o) > 0$. Suppose now that the regulatory policy is described by the pair (π_1, s_o), with $\pi_1 > \pi_o$. In this case, $-c_e(e) < \pi_1 f'(0) \leq \pi_1 f'(e - s_o)$ for all levels of emissions $e \geq s_o$. Then, the firm optimally chooses $e_1 = s_o$, and hence, is perfectly compliant. Finally, suppose that the regulatory policy is now the pair (π_o, s_1), with $s_1 > s_o$. In that case $-c_e(e) < \pi_o f'(0) \leq \pi_o f'(e - s_1)$ for all level of emissions $e \geq s_1$; the firm is compliant and optimally chooses $e_2 = s_1$.

Figure 1. A Firm's Compliance Decision Under an Emissions Standard



The model suggests that the decision of whether to violate the environmental standard is based on a simple comparison of marginal costs and benefits. The marginal cost of violating the environmental standard is the marginal expected penalty. The marginal benefit of a violation is the marginal reduction in abatement costs. When the marginal expected penalty exceeds the firm's marginal abatement costs for all choices of emissions above the standard, the firm chooses to be compliant. Otherwise, the firm chooses its emissions and resulting violation so that its marginal abatement costs are equal to the marginal expected penalty.

The model also suggests some simple comparative static results. It is clear that a non-compliant firm's violation is decreasing in the audit probability and the marginal penalty for an emissions violation. In fact, empirical studies that address compliance behavior and enforcement of actual environmental regulations tend to suggest that expected penalties have a positive deterrent effect [Cohen (1999)]. For example, in an empirical analysis of the United States Coast Guard's oil spill prevention program, Cohen (1987) found that oil spill size –the environmental regulation target- decreases with more Coast Guard observing patrols and observing transfer operations.[4] However, his results also show that inspection activities to determine compliance to oil spill prevention regulations have had no significant effect on spill size. More recently, using data on individual U.S. steel plants during the years 1980-1989, Gray and Deily (1996) found that, under different measures of enforcement activity, current and lagged enforcement of air pollution regulation increased compliance at steel plants. In another study, Laplante and Rilstone (1996) evaluated the impact of monitoring strategies on emissions of the pulp and paper industry in Quebec. Their results show that inspections and the threat of inspection have a negative impact on firms' emissions choices. Further, they also conclude that the benefits of inspections are not limited to reducing emissions, but more frequent inspections provide the regulator with more information because they induce firms to provide reports of their emissions more frequently.

2.2 Implications for monitoring strategies

The model of the previous subsection suggests that cost-effective enforcement of standard should involve targeted monitoring. For example, if the policy objective is to achieve complete compliance, the compliance condition (2.2) suggests that a regulator should set the audit frequency so that the marginal expected penalty of a slight violation is equal to the firm's marginal abatement costs at the standard. Clearly, given penalties

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[4] Coast Guard observing patrols refer to the activity in which Coast Guard personnel randomly patrol port areas to look for unreported oil spills. Observing transfer operations refer to the activity of Coast Guard personnel in which they selectively observe oil transfer operations while vessels are docked at ports [Cohen (1987)].

that are uniformly applied, those firms with high marginal abatement costs or that face stricter standards need to be monitored more closely than others.[5] However, to target monitoring perfectly a regulator must have perfect knowledge of the marginal abatement costs of all regulated firms. Acquiring this knowledge will be very difficult to obtain because it requires detailed information about each firm's operations.

Another sort of targeting is possible when firms are required to provide reports of their emissions. A large portion of all environmental policies in the United States require firms to provide regulators with reports of their emissions. A few authors have examined the role of self-reporting, and all have done so in the context of enforcing standards. Harford (1987) provides a positive analysis of firm behavior in this setting, while Malik (1993), Kaplow and Shavell (1994), and Livernois and McKenna (1999) all examine, from a normative perspective, the use and value of self-reporting in the design of optimal strategies for enforcing standards. Each of the normative analyses have found that self-reporting is valuable because the report provides information to the enforcement agency that can be used to target monitoring effort at specific firms. In the cases in which truthful reports of violations can be guaranteed –the models of Kaplow and Shavell, and Malik- the firms that report being non-compliant need not be monitored. Hence, self-reporting conserves enforcement costs because effort need not be spent identifying firms that are non-compliant –they identify themselves! Audits need only be conducted on firms that report that they are compliant. Even though truth-telling by all firms in all situations cannot be guaranteed in the model of Livernois and Mckenna, a self-reporting

[5] This result also holds in another policy context. Garvie and Keeler (1994) show that a budget-constrained regulator that wants to maximize compliance to emissions standards should direct more monitoring effort at firms with high marginal abatement costs.

requirement still conserves monitoring effort because some portion of non-compliant firms will truthfully report that they are non-compliant.[6]

2.3 Implications for setting penalties

Simple inspection of the compliance condition (2.2) confirms Becker's (1968) seminal insight about the tradeoff between monitoring and penalties in this context. If monitoring is costly but setting penalties is not, the enforcement cost of maintaining complete compliance (or any other level of compliance) can always be reduced by choosing higher marginal penalties and lower audit probabilities.

In practice, however, penalties are not set at maximal levels. And there are good theoretical reasons why they should not be set at high levels. Andreoni (1991) argues that judges and juries will be more reluctant to convict an offending party if doing so entails a severe penalty. Also, a violator's assets may not be sufficient to pay a high monetary penalty, and hence, the penalty itself may have a limited deterrent effect.[7] A particularly interesting literature suggests that high penalties may induce violators to

[6] Yet a third type of targeting is possible when an enforcement strategy is state-dependent. Harrington (1988) constructs a model in which firms are classified into two groups based upon their past compliance records. Those firms with good compliance records (good guys) face lower expected penalties than those with bad compliance records (bad guys). Firms with good compliance records are deterred from becoming non-compliant, despite low expected penalties, because they fear the higher expected penalties they would face if they were considered to be one of the bad guys. In this dissertation, I do not consider state-dependent enforcement of market-based policies.

[7] In these cases, a non-monetary penalty like incarceration may be appropriate. Segerson and Tietenberg (1992) consider the efficiency properties of incarceration for violations of environmental standards.

engage in costly activities to either contest enforcement actions against them, or to conceal their illegal activities.[8]

In practice, regulators often attempt to assess penalties for environmental violations that are based upon the economic gain to a violator of being non-compliant [Wasserman (1992), Segerson and Tietenberg (1992)]. Setting penalties in this way is meant to remove the incentive to violate a standard in the first place. It appears, though, that there is a serious information problem inherent in this approach. The marginal gain from violating a standard is a firm's marginal abatement cost, because this indicates costs the firm avoids when it decides to be non-compliant. Therefore, to assess a gain-based penalty when a violation is detected requires the enforcement authority to estimate a firm's emissions-control costs. Doing so, however, requires detailed information about a firm's operations, much of which will be hidden from the enforcers. In addition, it is clear that an offending firm will have an incentive to misrepresent any information it is required to provide to the enforcer.[9]

3. The Existing Literature on Enforcing Market-Based Environmental Policies

In this section, I review the existing literature on enforcement problems in market-based environmental policies. This literature is not large, and most of it does not

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[8] For theoretical analysis of contestability and avoidance activities see Kaplow (1990), Khambu (1990), Arye and Kaplow (1993), Heyes (1994), Nowel and Shogren (1994), Oh (1995), Huang (1996), and Jost (1997a, 1997b).

[9] Another important criterion for assessing environmental penalties is that penalties should be based on the environmental damage caused by a violation. This is also problematic from an information perspective because of the well-known difficulties with estimating environmental damages. Although damage-based penalties are an important aspect of actual environmental enforcement, they are not as important for my dissertation research as gain-based penalties.

deal directly with the design of appropriate enforcement strategies. Nevertheless, a number of important design implications have emerged. To motivate a discussion of these implications, I employ a simple model of a firm's compliance behavior in a competitive transferable emissions permit system.[10] This section concludes with a brief review of the literature that compares outcomes under market-based policies to command-and-control policies when firms may choose to be non-compliant.

3.1 A simple model of compliance in a transferable emission permits system

Throughout I consider a risk neutral firm that operates in a competitive transferable permit system, along with a fixed number of heterogeneous other firms.[11] Each individual firm is a perfect competitor in the license market, so the license market generates a license price p. Further, because I want to analyze intentional violations as opposed to violations that result from random acts of nature or equipment failures, I assume that emissions are deterministic.[12]

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.[13]

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[10] The model and results presented in this section are based largely on Stranlund and Dhanda (1999) and Stranlund (1998). The model is not unique in this literature, but there are differences. I will point out these differences as we proceed.

[11] Malik (1990) is the only work in this literature that considers non-neutral attitudes toward risk.

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

[13] 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.

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 $e - l = 0$. 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, I 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 $\pi f(e - l)$.[14]

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

[14] 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.

$$min \quad c(e, \alpha) + p(l - l_0) + \pi f(e - l) \tag{2.3}$$

$$s.t \quad e - l \geq 0.$$

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:

$$\theta_e = c_e(e, \alpha) + \pi f'(e - l) - \eta = 0; \tag{2.4-a}$$

$$\theta_l = p - \pi f'(e - l) + \eta \leq 0,\ \theta_l \times (e - l) = 0; \tag{2.4-b}$$

$$\theta_\eta = e - l \geq 0,\ \eta \geq 0,\ \eta \times (e - l) = 0. \tag{2.4-c}$$

Given the structure of abatement costs and expected penalties, conditions (2.4-a—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. First, 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, $p = -c_e(e, \alpha)$.[15] 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.

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.

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[15] A proof follows. Suppose that the firm is non-compliant so that $e - l > 0$. Then, (2.4-b) and (2.4-c) require $\theta_l = \eta = 0$. Thus, (2.4-a) becomes $c_e(e, \alpha) + \pi f'(e - l) = 0$, and (2.4-b) becomes $p - \pi f'(e - l) = 0$. Taken together, (2.4-a) and (2.4-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.

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.[16] It also has important implications for an enforcer's ability to target its enforcement strategy at different firms.

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 $p = \pi f'(e(p, \alpha) - l)$.[17] [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 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.

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

[17] To obtain this note from (2.4-b) and (2.4-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 $l = l(p, \alpha, \pi)$.

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

$$p \le \pi f'(0) .^{18} \tag{2.5}$$

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.[19]

3.2 Implications for monitoring

The results of our simple compliance model suggest a number of important implications for monitoring firms in competitive transferable emissions permit systems. First, note that the compliance condition (2.5) suggests that an enforcer that wants to achieve complete compliance while conserving monitoring costs should audit each firm

[18] 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.

[19] To see this result, denote a non-compliant firm's violation as $v = e - l$. When the firm is non-compliant, (2.4-b) and (2.4-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 $e_\alpha - l_\alpha = 0$.

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. 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 differences in marginal abatement costs among firms that the enforcement authority can exploit to target its monitoring effort. 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.[20] Since the latter pieces of information are not valuable, an enforcer faces no asymmetric information problems.

These results do not hold in the context of emissions standards. As I noted in the second section of this chapter, 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.

[20] 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 (2.4-a) through (2.4-c).

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.

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.[21]

3.3 Implications for setting penalties

The compliance condition (2.5) also suggests that a regulator may want to tie marginal penalties to the equilibrium permit price [Stranlund and Chavez (1999) 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 (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

[21] 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.

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.

3.4 Market effects

Enforcement of market-based environmental policies differs from enforcing command-and-control standards in at least one fundamental way. In a market-based system, firms' choices and characteristics are linked together by a permit market, whereas in a command-and-control system firms are more or less independent. In an unpublished working paper, Stranlund (1998) has examined some of the linkages among firms in a market-based system and their implications for enforcement.

On the issue of targeted enforcement, an enforcer that tries to induce greater compliance from a group of firms may increase the incentive for all others to be less compliant. When a group of firms is monitored more closely, they will reduce their violations by purchasing more permits. But this puts upward pressure on the equilibrium permit price. In turn, this increases the incentive to be non-compliant for all other firms. The cautionary note for enforcement policies should be clear: efforts to induce greater compliance by one group of firms will be partially thwarted because these efforts can lead to higher rates of noncompliance by all other firms. Furthermore, equilibrium violations of all firms are linked to the exogenous characteristics of each type of firm in essentially the same way –through the impacts these characteristics have on the equilibrium license price. Suppose, for example, that the marginal abatement costs of a group of firms fall, perhaps because they adopt a new emissions-control technology. These firms will reduce their emissions because it is now cheaper to do so, and hence, will reduce their demands for emissions permits. This puts downward pressure on the equilibrium permit price, which reduces the incentive to be non-compliant for every other firm.

These two market results suggest that an enforcer may wish to pursue non-traditional methods of enforcing market-based policies. In particular, public efforts to reduce abatement costs, like the provision of technological aid as in Stranlund (1997), may be good substitutes for direct enforcement efforts.[22]

[22] Stranlund (1997) considers the combination of technological aid with monitoring to achieve a desired rate of compliance in the context of firm specific emissions standards. He shows that technological aid is a policy substitute for monitoring effort because its provision reduces the required monitoring effort for the compliance goal. Furthermore, it also reduces the firms' expected compliance costs.

3.5 Enforcement of command-and-control and market-based environmental policies

A large portion of the small literature on compliance in market-based system compares outcomes in these systems to those in command-and-control systems. The primary message that emerges from this analysis is that the often-claimed superiority of market-based policies over command-and-control cannot be guaranteed when firms may be non-compliant and resources must be expended to enforce compliance.

For example, Keeler (1992) considers aggregate outcomes of environmental regulation (number of non-compliant firms, and aggregate emissions). Specifically, given a fixed enforcement program, Keeler (1992) shows that the aggregate level of emissions and the number of firms violating their legal rights to emit may be larger under a market-based environmental policy than under a command-and-control type of regulation, except for the case of a linear penalty function. With a somewhat different model, Hahn and Axtell (1995) find similar inconclusive results comparing aggregate abatement and aggregate control costs between market-based and command-and-control policies.

Both of the comparisons just mentioned were carried out under the assumption that enforcement is fixed for both regimes. In contrast, Malik (1992) chooses enforcement strategies that achieve complete compliance with least enforcement effort, and compares aggregate policy costs –aggregate abatement costs plus enforcement costs- under market-based and command-and-control policies. He finds that aggregate policy costs may be higher under market-based policies. Since aggregate abatement costs will generally be lower for market-based policies, higher aggregate policy costs must be due to substantially higher enforcement costs.