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Implementing Environmental Regulation: Enforcement and Compliance

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1. Introduction

The last three decades have seen the emergence of environmental regulation as a major activity of governments in the US and elsewhere. As the stringency of those regulations has increased so too has the incentive for non-compliance and the need to enforce.[1]

It is obvious that enforcement issues matter in designing and appraising any regulatory regime. Cost-benefit evaluation of a particular piece of regulation which implicitly assumes full compliance is likely to be misleading if ''slippage'' occurs during implementation—particularly if that slippage is substantial. Of course true compliance rates with regulatory requirements are often, by their nature, difficult to know with any certainty. Published government statistics need to be interpreted with care. ''Compliant'' is almost always the default categorization such that a polluting source being deemed compliant means only that the agency has failed to demonstrate non-compliance. (This can be a very different thing—a 1979 report by the General Accounting Office estimated that only 3% of sources designated fully-compliant with air pollution limits were actually compliant).[2] One well-known early study conducted by the White House Council on Environmental Quality (CEQ)—and reported in Russell (1990)—estimated the following rates of compliance with air pollution limits by industrial sources: percentage of sources in

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1 In the US, for example, the number of administrative actions in support of six major environmental statutes increased from 864 in 1982 to 3885 in 1988. Much of this extra effort was focussed on the toxic and hazardous substance programs.

2 Russell (1990) points to examples of how untrustworthy estimates of compliance rates can be. In the context of hazardous waste regulation in the US, for instance, he asserts that official documentation is '' . . . largely a catalogue of speculations about the possible extent of illegal disposal'' (page 261).

violation—65; percentage of time the sources were in violation—11; excess emissions as a percentage of standards—10. In the United Kingdom, *published* compliance rates with many key water quality standards are significantly below 100%, sometimes as low as 50%, and the *true* compliance rates are likely to be even lower.

The enforcement dimension of environmental regulation has been widely studied, as the (far from exhaustive) bibliography to this paper attests. The aim here is to survey some of that literature. The paper is organized as follows. Section 2 outlines a simple random monitoring model, with and without penalties being restricted. Section 3 identifies a number of ways in which the benchmark model has been extended and adapted to reflect alternative assumptions about objectives, instruments and exogenous constraints. Three strands are given particular attention—regulatory ''challenge'', the role of self-reporting and enforcement in multi-context/multi-period setting. Section 4 focuses on the role of private citizens (through market, political and extra-political channels) in the determination of compliance incentives—a popular topic currently. Section 5 provides a selective overview of some of the empirical work done to date in this field. Section 6 concludes and provides an opportunity to speculate about future directions that the literature might and should take.

2. The Benchmark Model

The basic approach to modeling compliance with an environmental regulation is a variant on the more general model of Becker (1968). Fines for law-breaking are treated as any other cost of doing business. Would-be polluters are assumed to act to minimize the sum of expected compliance costs plus expected penalties, with the efforts of the enforcement agency impacting the latter.

Suppose, initially, that the compliance decision is ''binary'', such as might be the case if a regulation requires a firm to install a well-defined and indivisible item of abatement equipment. Under standard simplifying assumptions, firm i will choose to comply if and only if its cost of compliance c_i is no greater than the expected penalty from non-compliance. If enforcement is by means of random inspection (which occurs with probability α) and lump-sum fine D, then firm i complies if and only if $c_i \leq \alpha \cdot D$. If c_i is distributed across the population according to the distribution function $f(c)$ (with associated cumulative $F(c)$) then the rate of compliance across the population, denoted Λ, will be $F(\alpha \cdot D)$. This yields the ''obvious'' comparative statics;

$$\frac{\partial \Lambda}{\partial \alpha} = D \cdot \frac{\partial F}{\partial c} \geq 0$$

and

$$\frac{\partial \Lambda}{\partial D} = \alpha \cdot \frac{\partial F}{\partial c} \geq 0.$$

Increasing either the rate of inspection or the size of penalty (weakly) increases population

compliance, with the size of that increase depending upon the distribution of firms by cost type.

Though the assumption of binary compliance makes things tractable, it is clear that many real compliance decisions are likely to be continuous. Consider a firm regulated by an emission standard which requires that its emissions, x_i, of some pollutant not exceed S. The firm's marginal cost of abatement is c_i and the expected penalty for non-compliance is described by $P(x_i, S)$ where $P_{x_i} \geq 0$, $P_S \leq 0$. In that case, the firm complies exactly ($x_i^* = S$) if c_i is less than some $\tilde{c}$, otherwise it violates, choosing a level of emission implicitly defined by

$$P_x(x_i^*, S) = c_i.$$

Importantly, though the *level* of penalties impacts the decision about whether or not to violate, once the decision to violate has been made the decision about the extent of violation depends only upon the *marginal* properties of the penalty function.[3] This is the ''principle of marginal deterrence'' (Shavell 1992; Friedman and Sjostrom 1993 etc.). Failure to understand the principle underpins many of the apparent paradoxes of observed behavior—(e.g. that raising the *level* of penalties may worsen compliance).

So far it has been assumed (implicitly) that $P(x_i, S) = 0$, $\forall x_i \leq S$—the enforcement process never mistakenly penalizes a compliant firm. Under monitoring uncertainty type II errors of this sort may, of course, occur and the standard analysis can straightforwardly be extended to take account of them (e.g., Segerson 1988 and Xepapedeas 1997).[4] One of the most significant implications of such an extension is the possibility that low-cost firms may find it optimal to *over*-comply with the regulatory requirement to reduce the probability of wrongful penalty below what would be implied by exact compliance.

2.1. Restricted Penalties

In a simple random inspection model the structure of expected penalties—the form of P—can be affected by manipulating either inspection rates or nominal penalties or both. Full compliance across the population is achieved by setting P at some arbitrarily high level. In many settings, however, there will be an upper bound on the penalty that can be levied.

There are a variety of reasons why such restrictions may apply. ''In most states there is a restriction on the size of the penalty that can be levied . . . (E)ven when a maximum fine is not imposed by statute there may be a practical or political limit to the size of penalties.

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3 This is not, in fact, that surprising—and is analogous to the distinction between fixed and variable costs in first-year industrial economics. The magnitude of fixed costs effects the participation decision, but not the choice of level of output by those that are participant. The implications of the ''jumping'' of firms between complier and non-complier paper was analyzed in the classic paper Viscusi and Zeckhauser (1979).

4 See, for example, Segerson (1988) figure 1. Segerson's paper also makes a sharp distinction between single polluter and multiple polluter settings, and the problems that arise in the attribution of blame in the latter case.

Severe but rarely used penalties might seem capricious and unfair'' (Harrington 1988: 32). The wealth constraint of a firm also puts a natural upper cap on how much a firm can be fined or held liable for. Impositions beyond that cap render the firm ''judgement proof'' (Shavell 1986). The difficulties arising from the judgement proofness problem have been analyzed by Heyes (1995), Beard (1990) and others.

Ringleb and Wiggins (1992) argue that ''strategic subsidiarization''—the practice whereby a large corporation puts their most environmentally-risky activities into a wholly-owned but low-asset subsidiary, so as to insulate the assets of the former from the environmental mis-doings of the latter—renders this upper bound on penalties endogenous, and provide empirical evidence of the significance of the practice in the US.

3. Moving on from Basics

The benchmark model incorporates a plethora of simplifying assumptions and a lot of effort has been applied in understanding the implications of relaxing some of those assumptions. Several important ones are considered here.

3.1. Inspectability and Contested Enforcement

Up until now the enforcement agency has been assumed able to (i) inspect the regulated firm and (ii) levy a penalty against those found non-compliant. In the real world—and especially, perhaps, in the US—the Agency's powers are not as assured as such a model would suggest, and affected parties are able to obstruct the enforcement process and challenge regulatory decisions through various channels. (Nowell and Shogren (1994: 265) preface their paper with a 1994 quote from the then EPA Administrator William Reilly: ''Four out of every five decisions I make are contested in court'').

Endogenizing such obfuscation and challenge can be expected to alter the results of standard analysis, and in some cases qualitatively reverse them.

It is useful to distinguish between actions that the regulated firm takes (or might take) before from those taken after the EPA brings an enforcement action.

Heyes (1993) develops a model of regulatory enforcement when inspectability is endogenous. In most settings the monitoring technology available to EPA inspectors is inaccurate, such that even if a firm is failing to comply with some regulatory requirement when inspected, the inspection may still fail to detect that non-compliance. Clearly the enforcement agency can reduce that likelihood—at a cost—by increasing the thoroughness of its inspections, and part of characterizing an optimal enforcement program would be to specify the ''right'' degree of thoroughness.[5] Heyes contends, further, that firms may be able to *increase* that likelihood by investing in ''uninspectability''.

There are a variety of ways in which firms might invest in reducing the transparency of their operations and so reduce their inspectability in the sense defined. Consider, for

5 This could involve using more sophisticated monitoring equipment, taking more samples per inspection-site etc., depending upon context.

example, the possibility of a firm setting up so-called ''sanitized areas'' that are essentially dummies—operationally-redundant but environmentally-benign parts of a plant. If inspection is seen as a sampling game in which the inspector tries to find a non-compliant part of a plant (the illegally set effluent outlet among the twenty properly set ones, for example) then the firm can decrease the probability that he does so simply by increasing the number of sanitized areas. The spending associated with this type of '' . . . attempt to change operations in order to pass on-site inspections'' (Linder and McBride 1984) would constitute one type of investment in uninspectability. In the US a firm's constitutional right to privacy under the 4th amendment means that EPA inspectors are obliged to conduct at least the initial rounds of their inspection from outside the firm's perimeter fence using remote sensing devices. If the ability of such devices to detect violation decreases with distance (as seems plausible), then the firm can invest in uninspectability simply by buying more land—putting greater distance between the source of the pollutant in question and the nearest point from which surveillance can legally be conducted. More generally, inspectability could be seen as an embodied characteristic of capital (some types of plant are inherently easier to inspect than others) such that its endogeneity arises inevitably from the fact that firms have choice of technique.

Analytically Heyes assumes the probability that an inspection will detect an incident of non-compliance at a plant can be described by the function $p(t, n)$ where t is the thoroughness of the EPA's inspection procedures and n is the ''investment'' of the firm in ''uninspectability''. He shows that increasing the *thoroughness* of inspections induces firms to substitute towards more transparent technologies, whereas increasing their *frequency* causes substitution the other way.[6] Perversely, once the effect of such substitution is taken into account, an increase in the frequency of inspections (or, equally, the stringency of penalties) may worsen the firm's environmental performance. The policy implication is that the agency should favor more thorough but less frequent inspection than existing theory (models with n fixed) suggest, particularly in sectors where the scope for such substitution is great.[7]

Malik (1990) uses a model in which offenders can, similarly, engage *ex ante* in activities which serve to reduce the probability of being caught and fined. He argues that the costs associated with such activities can provide an incentive for screening by the agency in settings where it not optimal to deter all offences.

Other papers consider the implications of the recognition that enforcement actions *once taken* may be subject to challenge. These include Kambhu (1989, 1990), Kadambe and Segerson (1998), Jost (1997), and Nowell and Shogren (1994).

In a simple but insightful paper Kambhu (1989) investigates the impact of assuming firms able to engage in activities to erode the penalty they end up paying for an infraction

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6 The result is driven by the assumption that the cross-partial p_{nt} is positive—increasing the thoroughness of inspection serves to reduce the marginal productivity of expenditures on n.

7 Heyes also argues that when inspectability adjusts only sluggishly to policy shocks (because, say, it is an embodied characteristic of capital) the environmental impacts of increasing frequency and increasing thoroughness will over- and under-shoot their respective long-run impacts. The possibility of overshooting is presented as an alternative to ''capture'' theories of why the efficacy of some classes of regulatory reform may be seen to ''fade'' through time.

of a particular size—arriving at some strikingly unconventional conclusions. This might be investing in good lawyers to ''talk down'' the offence in court (a sub-title of the paper is ''raise your standards and you'll hear from my lawyer'') or might take other forms.

Analytically, Kambhu supposes that by investing h in such activities the firm is able to avoid a portion $(1-\beta(h))$ of the fine $f\cdot(s-a)$ which it should pay if the abatement it does, a, is less than what is required, s. The (interior) solution to the firm's problem, $\{a^*, h^*\}$, is defined by a pair of first-order conditions:—

$$c' = f\cdot\beta$$

and

$$\beta'\cdot f\cdot(s-a) = -1.$$

Both have obvious interpretation. Partial differentiation of the first of these (i.e. with h fixed) implies $\partial a^*/\partial s = 0$ and $\partial a^*/\partial f = (\beta/c'') > 0$. Application of Cramer's rule to the pair, however, yields

$$\frac{da^*}{ds} = \frac{-f\cdot(\beta')^2}{|\Delta|},$$

(where $|\Delta|$ is the determinant of the system and is positive) which is strictly negative—reducing the stringency of the standard (lowering s) induces an unambiguous improvement in the environmental performance of non-compliant firms (an increase in a^*).

Though the lack of ambiguity results from Kambhu's particular framework (in particular the assumed linearity of the penalty function) the basic insight is a useful one. In many settings a firm will have two ways to reduce the penalties it pays: (a) by cleaning-up its operations so reducing the penalties for which it is liable, and (b) by spending on lawyers to reduce that share of those penalties for which it is liable that it ultimately pays. Conventional analysis ignores (b) such that reducing s leads to a fall in a. With h endogenous, however, it is straight-forward to note that

$$\partial h^*/\partial s = -f\cdot(s-a)\cdot\beta_{hh}/\beta_h > 0.$$

A reduction in s also leads firms to reduce their expenditure on lawyers, increasing the *effective* marginal penalty for under-compliance and so inducing an off-setting increase in a. Depending upon the specification of functions there is no reason to rule out the case in which the latter indirect effect outweighs the direct effect (the particular specification devised by Kambhu gets rid of the direct effect securing an unambiguously perverse result).

The result implies that a relaxation of standards might improve environmental performance. Conversely a ratcheting-up of those standards could end up worsening performance (or, at least, improving it by less than standard h-fixed analysis would

suggest). Kambhu uses the model to justify the sort of ''shadow'' or informal standards that regulators are often claimed to apply.[8]

The interest in Nowell and Shogren (1994) is underpinned similarly. They envisage a two-stage process with the agency moving first. The agency sets the levels of three instruments—the level of monitoring, m, the per unit fine for illegal dumping, F, and the cost of legal dumping, L. The firm then chooses how much illegal dumping, α, to do and how much resource k to commit to contesting enforcement actions against it. The probability of any illegality being penalized is summarized by some function $p(m, \alpha, k)$. Simple comparative static manipulation yields ''*Proposition 2:* Assuming fixed output in an agency-leader framework, if the firm's ability to challenge enforcement is endogenous, a reduction in illegal dumping is guaranteed by a reduction in the cost of legal dumping. Increasing the fine or probability of being fined could result in increased illegal dumping'' (Nowell and Shogren 1994, page 270).

The ambiguity of the impact of an increase in inspected fine upon performance mirrors that of Kambhu, and has a similar rationale. The increase has the 'usual' direct effect which works in the right direction, but an additional indirect effect through induced increases in the propensity to challenge enforcement which works in the opposite direction. Which effect dominates cannot, in general, be established and depends upon the specification of $p(m, \alpha, k)$—in particular the size of two of the cross-partials.[9]

Nowell and Shogren extend their analysis usefully to the case of multiple polluters in which each firm attempts to challenge any determination of its ''contribution'' to aggregate damage. This sets firms in competition with one another—trying to deflect blame for pollution onto others—and adds some interesting wrinkles to the single-firm case. It is shown (see their Proposition 3, page 278) that observable and credible commitment to challenge a regulation leads to (a) over-investment of resources to evade enforcement and (b) an increased level of illegal dumping by both firms. When blame for some aggregate damage is only imperfectly attributable (and that attribution can be influenced by expenditure on challenge) α_i and α_j are shown to be strategic substitutes and firms to overinvest in (mutually off-setting) increases in k.[10]

The policy implications drawn by the authors of these and related models have invariably been drawn *within* the constraints of the model—i.e. they have related to the use of enforcement instruments *given* the process of ''challengeability''. The analyses also have institutional-design implications. Insofar as the existence of channels of contest imply systematically lower expected welfare, reforming the processes and institutions of enforcement to remove or restrict those channels could be desirable.

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8 Kambhu also reports a potentially perverse result with respect to increases in the unit penalty f. Placing the (rather weak) restriction of log-concavity of the β function is sufficient to rule this out.

9 The ambiguity can be removed (as the authors acknowledge), such that the first effect dominates the latter, by specification of an appropriate non-linear penalty function (see also Shaffer (1990a)).

10 A cooperative solution amongst the firms would be an agreement to both commit to lower levels of k. Coordination of such agreements could be one function of an industry body and (unlike collusive pricing agreements in standard cartel theory, for example) would be welfare-enhancing and hence encouraged by regulators.

3.2. Self-Reporting

The benchmark model of section 2 treated the inspection process as being random. It can be extended to the case in which the EPA conditions inspection probabilities upon observable characteristics of the firm (size, location etc.) with obvious results. As well as conditioning on exogenously-observed characteristics, however, an enforcement agency might also require regulated firms to self-report compliance status, and condition verification on the content of those reports.

Many modern environmental enforcement programs incorporate an element of self-reporting. (Russell (1990) found that, on average, state environmental agencies in the US required 28% of air pollution sources and 84% of water pollution sources to self-report.) The model needs significant revision if the incentive implications of this are to be understood. The firm now has to decide not just what to do, but also what to report that it is doing. The EPA has to decide how to interpret and respond to those reports.

Most of the pioneering work on self-reporting has been developed in the context of tax compliance, but can be applied more generally. Seminal contributions include Allingham and Sandmo (1972), Greenberg (1984), Srinivasan (1973), Reinganum and Wilde (1986) and Graetz, Reinganum and Wilde (1986).[11]

The standard reference on the role of self-reporting in legal enforcement is Kaplow and Shavell (1994).[12] They argue that self-reporting schemes improve upon simpler random inspection schemes for two reasons: (a) enforcement resources are saved because those who report their harmful acts no longer require detection and, (b) risk is reduced (assuming risk averse regulatees) because those who self-report violations bear certain rather than uncertain sanctions.

Malik (1993) uses a more complex principal-agency framework in which both auditing and sanctioning are costly, and monitoring technology is noisy, to characterize and compare incentive-compatible regulatory policies with and without self-reporting in a world in which pollution is stochastic. He fins that firms need to be audited less often when self-reporting is required, but punished more often. The normative results are—unsurprisingly—ambiguous. The sign and size of the welfare gains from self-reporting depend upon the relative size of the audit and sanction costs, the accuracy of the regulators monitoring technology, and the desired level of abatement effort.

Livernois and McKenna (1999) use the institution of self-reporting to offer an explanation for the empirically puzzling stylized fact that so many firms comply with pollution emission standards even though the expected penalties for noncompliance are so

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11 For an excellent survey the reader is directed to Cuccia (1994). The tax enforcement literature is extensive (Cuccia cites over 100 journal articles) and we only mention those of most particular relevance to the current context.

12 The interested reader is also directed to Kaplow and Shavell (1991). A model of self-reporting with explicit application to environmental regulation is Harford (1987). He presents a simple model in which the firm chooses a level of emission (subject to an emission standard) and a level report. When the penalty function for violation of the pollution standard is linear in the size of the violation it turns out that actual pollution is insensitive to the level of the standard (this has come to be a well-known characteristic of models of this sort—as in Kambhu's (1989) fixed-h case above).

low.[13] They show that allowing for self-reporting may be sufficient to overturn the conventional wisdom that higher fines should lead to higher compliance. The mechanism is similar to that identified by Friedman and Sjostrom (1993), Heyes (1996) and others in the context of other compound offences.

In Livernois and McKenna there are two offences that are compound: (a) noncompliance with a standard (which occurs if an ''abatement machine'' get unplugged—deliberately or accidentally) and (b) failure to report non-compliance. The first is bad for the environment for obvious reasons. The second is bad because reporting also implies having to plug the machine back in (which the firm might not otherwise do since so doing implies a cost). The regulator doesn't want to penalize non-compliance too harshly because then no-one will self-report and a higher proportion of machines will be left un-repaired. As such the model is a neat and straight-forward application of the principle of marginal deterrence and the need to maintain a sufficiently steep penalty gradient even if that means lowering the fine imposed for ''stage one'' wrongdoing.[14]

An intriguing recent extension of the self-reporting literature is that of motivational heterogeneity. All of the contributions cited to now have assumed that the firm is a rational liar—happy to report dishonestly when pecuniary considerations suggest such dishonesty would pay.[15] Interestingly, some of the basic conclusions derived from standard analyzes of enforcement regimes with a self-reporting element break-down if some (not necessarily large) subset of firms are routinely honest in their reporting practices.

There is good anecdotal and empirical evidence for making such an assumption. Typically, setting all of the enforcement variables equal to zero in an econometrically-estimated reporting function does not yield zero reporting but rather some (positive) ''unenforced'' reporting residual. Given that most concepts of ethics are framed at the individual level it is useful to distinguish between individual and corporate honesty. The former may, however, be a key determinant of the latter. In the context of honesty of environmental reporting practices in the US Dimento (1986: 84) emphasizes ''the idiosyncracies of top management''. It is possible that a firm's motives for honesty may be self-serving—it may, for example, have employees or clients particularly unwilling to tolerate unethical behavior.

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13 This is an observation that Heyes and Rickman (1999) have referred to as the ''Harrington Paradox''. We return to it in detail below.

14 The logic underlying Heyes (1996) is more or less identical (and will be explained in more detail below). The Coastguard (for example) would not wish to have penalties for oil-spills be too heavy because captains of oil tankers would then fail to report spills that did occur (in the hope of liability for the spill never being attributed) and hence make prompt mitigative measures less likely. Some authors have considered the interaction between abatement and clean-up decisions more generally—Shaffer (1990b) is a good example.

15 Economists are entirely used to and comfortable with making assumptions of this sort (it is not for nothing that our science is deemed dismal by many). As Frank Cowell notes in his book: '' . . . the expression predisposed to dishonesty is used because we do not impute to the taxpayer any views about duty, honor or civic pride that would compel him to put some responsibility to the state or greater good ahead of his own money-grubbing interests. Whilst virtue for its own sake would be laudable, it is unexciting in terms of economic content'' (Cowell 1990: 50).

Erard and Feinstein (1994) argue, correctly, that incorporating a subset of ''pathologically honest'' reporters is one way to bring conventional models more closely in line with observation. Heyes (1999) considers the impacts of such motivational heterogeneity for welfare and instrument choice.

This is a potentially rich area of research, and it is likely that future work will allow for increased subtlety of how the motives of regulated firms are modeled. Frey (1992), in one of a series of papers, has propounded the notion of ''motivational crowding-out''—whereby people become less likely to do something voluntarily as efforts to coerce them into so doing are ratcheted-up.[16] The interested reader is also referred to Scholz (1984) and Haltiwanger and Waldman (1991, 1993).

3.3. Multi-Period and Multi-Context Contact

The basic model implicitly assumes that the enforcement agency and firm (a) interact only once and (b) interact in only one context. Neither of these is realistic.

Repeated playing of the enforcement-compliance game provides scope for the behavior of one or both players in any given play to be sensitive to previous actions and/or outcomes.

A variety of papers in the ''straight'' law and economics literature model the treatment of repeat offenders (e.g., Polinsky and Rubinfeld 1991). More sophisticated attempts have been made to use Markov models to characterize optimal state-dependent enforcement strategies when penalties are restricted, and these are likely to be particularly applicable in regulatory enforcement settings. Such regimes typically involve some degree of 'forgiveness' and are able to accommodate occasional type I monitoring errors.

Though the contributions of Greenberg (1984) and Landsberger and Meilijson (1982) are motivated by the income tax setting they have more general application, and are adapted to the context of pollution enforcement by Harrington (1988).

In a repeated, binary enforcement/compliance game with restricted penalties the EPA maximizes the rate of steady-state compliance, it can be shown, by operating a state-dependent enforcement regime. In the simplest case the agency groups sources according to recent inspection history—group 1 containing firms found to be compliant at last inspection, group two those found non-compliant—and levies no penalty upon a group 1 firm caught violating but a maximal penalty upon a group 2 firm caught likewise. In equilibrium a representative firm can be induced to comply a significant fraction of the time (i.e. whenever they find themselves resident in group 2) despite penalties never actually being levied.[17]

The model can this be used to ''explain'' the paradox with which Harrington opens his paper, namely that despite the fact that (i) when the USEPA observes violations it often (almost always) chooses not to pursue the violator and, (ii), the expected penalty faced by a violator who is pursued is small compared to the cost of compliance, it is still the case that, (iii), firms comply most of the time.[18]

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16 This is a phenomenon apparently widely known and accepted in psychology, and has been used by Frey to ''explain'' a number of otherwise surprising institutions and practices in a variety of settings.

17 Though the note by Raymond (1999a) questions the generality of the result.

18 Such (apparent) overcompliance has been observed in a variety of contexts by a number of authors. Harrington (1988) provides evidence of these and other stylized facts on pages 29–32, especially table 1

A firm can be induced to comply some of the time even though the limit on penalties is such that if all violations were penalized with certainty it would never do so. The (crude) state-dependent regime described generates ''penalty leverage''. When in group 2 a source's incentive to comply is not just the maximal penalty which it avoids but also the present value of reinstatement to group 1 and the laxer treatment which that entails in the next period.

The optimal (compliance-maximizing) state-dependent policy can be characterized by refining the crude regime described here to allow for differential rates of random inspection among group 1 and group 2 firms, and by making reinstatement to group 1 less-than-automatic.

The two most significant extensions made to this base model are due to Harford and Harrington (1991), who allow the EPA to set the *stringency* of the regulation being enforced in addition to the enforcement parameters, and Greenberg (1984) who allows for a third, absorbing state into which group 2 firms are cast if they are caught re-offending.[19]

Heyes and Rickman (1999) provide a cross-sectional analog to Harrington's model—consistent with the same set of stylized facts that motivated Harrington—in which an enforcement agency exploits issue-linkage opportunities.

The underlying assumption driving their results is that the EPA typically interacts with a particular firm in more than one enforcement ''domain''. This is realistic. It may be that the agency enforces the same rule at more than one plant of a multi-plant firm, or in more than one geographical area in which the firm operates. It may, equally, enforce several different sets of regulations—those regarding airborne emissions, waterborne discharges, noise etc.—at a single plant (see e.g. Yaeger 1991; Russell 1990). In that case, when penalties do not permit full-compliance to be achieved, the EPA may be able to improve upon the population compliance rate achieved by a policy of full pursuit (penalizing all violations with certainty) by engaging in ''regulatory dealing''. A regulatory deal involves agreeing (perhaps tacitly) to tolerate non-compliance in some sub-set of domains in ''exchange'' for compliance in others.

Consider a two domain world in which the periodic cost of (binary) compliance by firm i in domain j is c_{ij} for $j \in (1,2)$, and the maximum penalty for violation is Λ. If, for illustration, $c_{i1} = c_{i2} = 15$ while $\Lambda = 10$ it is apparent that a regime which detects and penalizes every violation will induce a zero rate of compliance. The firm's decision problem is separable by domain, and in each domain it will violate since $c_{i1}, c_{i2} > \Lambda$. When offered a deal (which amounts to, in words, ''comply in one domain in exchange for us turning a blind-eye to violation in the other'') the firm accepts (since $\min(c_{i1}, c_{i2}) < 2\Lambda$)—

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and surrounding discussion. To take a typical example—Connecticut—from that table, over the sampling period of 800 known violations (i.e. cases where Notices of Violations (NOV's) were issued) in an average year, penalties were assessed in only 21 cases, and the average penalty in those cases was a meagre $221. See also Hawkins (1983) for some early British evidence and Russell (1990).

19 State-dependence results in firms with identical abatement cost functions polluting at different levels and thereby fails a cost-effectiveness test. Harford and Harrington (1991) show that a state-dependent regime with a modified standard will often yield a lower sum of pollution control and monitoring cost for a given level of pollution control. See also Harford (1991) for an adaptation of the model to the case in which monitoring is subject to error.

saving penalty in both regimes in exchange for compliance in one—increasing its global rate of compliance from zero to 50%.[20]

Of course the EPA will not, in general, know the values of c_{ij} and so cannot target the firms with which it offers to deal. Dealing will improve a firm's compliance rate from 0% to 50% if

$$\Lambda < \min(c_{i1}, c_{i2}) < 2 \cdot \Lambda,$$

(an example of this was provided in the last paragraph). It will, however, worsen it from 100% to 50% if

$$\max(c_{i1}, c_{i2}) < \Lambda.$$

Denoting the cumulative distribution of c_{ij} as F, then the policy of dealing will improve population compliance rates if and only if the probability of the former

$$\alpha(\Lambda) = 2 \cdot (1 - F(\Lambda)) \cdot (F(2\Lambda) - F(\Lambda)) - (F(2\Lambda) - F(\Lambda))^2,$$

is greater than the probability of the latter

$$\beta(\Lambda) = F(\Lambda)^2.$$

This will depend upon the parameters of the model and the form of F. Interestingly, the gains from dealing are not necessarily increasing in the extent to which penalties are restricted (Proposition 2).[21]

So does the USEPA—or its counterparts agencies in other countries and other enforcement settings—exploit opportunities for penalty leverage or regulatory dealing? The two models are not, of course, mutually exclusive. It is realistic to suppose that the EPA in the US interacts with most firms both across a variety of enforcement contexts and through time such that it could exploit both. In that case specification of optimal policy would permit the Agency to condition its enforcement stance in domain i in period t not only upon the firm's compliance-history in domain i but also its past and current performance in domain j. Heyes and Rickman (1999) argue that there is empirical evidence to suggest use of both. More generally, the models can be seen as attempts to formalize the type of horse-trading and bargaining that routinely goes on between

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20 Implying, note, the type of overcompliance consistent with the stylized facts. If every firm was like this firm then a compliance-maximizing policy (characterized, as it would be, by dealing) would yield substantial compliance (50%) despite penalties never actually being levied. An external observer would calculate the expected benefit to compliance to be zero and so find the firms behavior paradoxical in the sense of Harrington.

21 If, for instance, $c_{ij} \sim U[0, 1]$, then the gains from dealing can be shown to be non-monotonic in Λ reaching an interior maximum of $(d/4)$ at $\Lambda = 1/4$ (i.e. if Λ happened to equal 1/4 the dealing would deliver a 25% improvement in population compliance over the becnhmark of a full-pursuit regime).

inspectors and sources, compelling institutional evidence for which is catalogued by Yaeger (1991), Hawkins (1983) and others who have presented accounts of what ''really happens'' inside regulatory agencies.

3.4. A ''Smorgasbord'' of Further Extensions

Other extensions include the following, though the list is far from exhaustive.

The regulated firm's objective function has been reformulated to incorporate risk aversion (e.g., Sandmo 1998).

The firm has been assumed to be informed only imperfectly about enforcement probabilities (Bebchuk and Kaplow 1992) or legal standards (Craswell and Calfee 1986). That uncertainty may reflect perception error (as in Bebchuk and Kaplow) or may reflect deliberate randomization on the part of the regulator (as in Craswell and Calfee (1986), and Chu (1993)).

The motivation of regulatees may be more complex than suggested by simple expected cost minimization. Frey (1992) analyzes the impact of ''intrinsic motivation'' to behave in a socially beneficial way and—most especially—the impact of the recognition that such motivation may be crowded-out or diminished by the use of coercive instruments of enforcement.

Scholz (1984) contends that people are more likely to comply with a requirement when those around are also compliant. Such motivation can serve to make compliant behavior ''infectious'' and cause regulatory agency's to want to have intermittent bursts of very intensive enforcement activity rather than stationary programs (see Chu (1993) who coins the phrase ''oscillatory enforcement'').

Whereas the great majority of the literature (including every paper discussed so far) focus on agency problems in the relationship between the EPA and the regulated firm—the latter being treated as a ''black box''—Gabel and Sinclair-Desagne (1993) and Segerson and Tietenberg (1992) examine agency problems *within* the firm, and how intra-firm considerations might make a restructuring of penalties desirable. Levying a penalty upon the shareholders of a firm, for example, will only be useful insofar as those shareholders (as principals) have sufficient instruments to allow them to influence the environmentally-relevant aspects of the behavior of their employees (agents). It is straight-forward to construct cases where the enforcer might prefer to 'cut out the middle man' and target the employee directly. The most widely-publicized approach to targeting individuals—and in a means which prevents transfer (though not necessarily compensation)—is imprisonment, and the growing trend towards criminalization of environmental non-compliance, particularly in the US, remains one of the most contentious political debates in this field.[22] Schwartz and Orleans (1967) have argued for the use of moral suasion in encouraging compliance.

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22 See the contributions to Tietenberg (1994) for some interesting general analysis of the role of criminal penalties and Earnhart (1996) for an application to an economy in transition.

4. Various Roles of the Private Sector

Recent years have seen growing support among policy-makers and pundits for increasing the role of individual citizens in regulation, and the regulatory enforcement process in particular (see Tietenberg 1998).

There are a variety of channels through which citizens might be expected to participate in or influence the enforcement of environmental requirements: (i) Political behavior, (ii) Market behavior and (iii) Direct participation.

The first channel is the most obvious—citizens impact environmental enforcement (as they do other aspects of policy) through their voting decisions. A sizeable empirical literature exists on the determinants of voting.

A private individual might also influence compliance behavior through market interaction with sources in his or her capacity as employee, investor or customer (see Grabosky 1994). Voluntary (unenforced) compliance may, in many contexts, be a profit-maximizing strategy. It is the notion that firms can be ''shamed'' into improving compliance that underlies the so-called ''third wave'' instruments which involve making information about the environmental performance of firms more easily accessible (see Tietenberg (1998) and citations there-in). The first- and second-wave instruments are the command-and-control and market-based instruments respectively. The efficacy of one ''third wave'' application (the Toxic Releases Inventory in the US) has been investigated by Khanna and Quimio (1997).

Under some pieces of legislation there exist channels for citizens (either individually or in groups) to participate more directly and explicitly in the enforcement process. In the US Naysnerski and Tietenberg (1992) and others have noted that the USEPA increasingly relies upon private litigants to bring suit against polluters.

In the case of the US Clean Water Act in particular, private litigation now constitutes a major component of the overall enforcement effort. In its 1993 Green Paper EC93(47) the European Commission clearly signalled its desire to ''beef-up'' the rights of individuals and environmental groups to pursue polluters to ensure compliance and restoration.[23] Specific authorization of citizen suits is provided by a number of the major environmental Acts in the US, including the Clean Water Act (section 505), Clean Air Act (section 304), Endangered Species Act (section 11(g)), Safe Drinking Water Act section 1449) and Toxic Substances Control Act (section 20).

Little formal modeling has been done on the likely role of private actors in the enforcement process. Conventional economic wisdom would suggest that because the environmental benefits of effective private enforcement are a public good there will be an *under*-provision of private enforcement effort for the standard reasons.

Heyes (1997), in contrast, provides a formal lottery-auction-based model of the interaction between private NGOs and regulated firms and establishes, in fact, the possibility of *over*-provision. In cases where there exists a welfare benefit from compliance private enforcement effort generates a public good, in other cases where

23 Note that these sorts of suits are over and above the ''usual'' cases in which specific individuals impacted by pollution sue for compensation for their private damages.

compliance implies a welfare loss (because of high firm-specific compliance costs, for example) that effort generates a public *bad*. The welfare effect of NGO intervention on balance is in theory, then, ambiguous. In practice the relative numbers of the two types of case will depend upon how discriminating the public agency's program is, and the resulting extent to which those cases left unenforced tend to be the cases where enforcement would be welfare-reducing.

Naysnerski and Tietenberg (1992) provide a good statement of the conventional wisdom in the environmental setting. They also argue that public and private enforcement efforts are likely to be substitutable and additive—implying that in a world in which enforcement is incomplete, the addition of a private enforcement program to an existing public program must increase the compliance incentives: ''Since the rise of private enforcement increases the likelihood that violations will be detected and prosecuted, it increases observed compliance with regulations'' (Naysnerski and Tietenberg 1992: 43).

This is self-evidently true in a world in which the EPA operates a random enforcement program and is resource constrained. If the EPA does anything more subtle than this—exploit penalty leverage, or engage in regulatory dealing, for examples—however, the incentive impact may be perverse. In both Harrington (1988) and Heyes and Rickman (1999) the compliance-maximizing agency lets known violators off without penalty because and only because it is compliance-enhancing to do so—this is the interesting feature of those papers, and the associated strands of literature. Private intervention in either of those cases could be expected to weaken population compliance rates and damage the environment.

5. Empirics: A Whistle-stop Tour

An empirical literature on compliance and enforcement in the environmental setting has developed in parallel to the theoretical work which has been the focus here. The development and assessment of that latter must, of course, reflect the findings of the former. At the same time the direction of the former must be underpinned by the latter. A brief description of some of the key strands of the empirical research program is provided here.

The ''bread and butter'' of empirical analysis in the field is the estimation of compliance and enforcement functions. Gray and Deily (1996), for example, use air pollution data from the US steel industry to estimate plant-level compliance and enforcement functions. The authors use state-of-the-art econometric techniques, and provide excellent discussion of many of the econometric issues that arise in this type of work.

In terms of their results, they find the ''expected'' interactions: greater enforcement leads to greater compliance, while greater compliance leads to less enforcement. Firm characteristics have surprisingly little impact on compliance decisions (see their table 3, page 107): neither firm size, diversification, nor gross cash flows were significant. The do

24 This is consistent with Dimento's (1986) assertion that the idiosyncracies and personalities of senior staff matter in determining a firm's compliance attitude.

find evidence of a ''residual corporate attitude towards compliance'' even after controlling for plant and firm characteristics.[24]

On the enforcement side (table 4, page 109) regulators exert less pressure on plants expected to be in compliance, towards plants in financial distress (see also Deily and Gray (1991)) and plants located in attainment areas, exerting more pressure on plants producing large absolute amounts of pollution, regardless of their compliance status. Interestingly, local labor market conditions had mixed effects, with less enforcement at plants that were large local employers, but more at plants in counties with high unemployment rates. In terms of firm-level effects, larger firms, those owning more than one steel plant, firms specialized in steelmaking and those with lower gross profit margins faced significantly laxer enforcement.

Other good examples of this type of study include Regens et al. (1997), Laplante and Rilstone (1996), Harrison (1995) and Fuller (1987). Epple and Visscher (1984), in a well-known early analysis, study the occurrence, detection and deterrence of marine oil spills.[25] Feinstein (1989) uses data from over 1000 NRC inspections to (jointly) estimate the occurrence of violations, inspections and abnormal events at nuclear power plants. Feinstein pays particular attention to the econometric problems arising from non-detection and is able to construct variations in ''propensity to detect'' at the individual-inspector level.

Related studies which have focussed more particularly on the efficacy of EPA enforcement programs include Magat and Viscusi (1990) (who study compliance with industrial effluent standards) and Nadeau (1997) (who focuses on the EPA's effectiveness in reducing the *duration* of plant-level non-compliance). Nadeau's results are particularly novel. Treating non-compliance as something with endogenous length—rather than a momentary occurrence—he uses parametric survival techniques to estimate that a 10% increase in EPA monitoring activity leads to a 0.6–4.2% reduction in expected violation time. The same increase in enforcement activity results in a 4–4.7% reduction.

Helland (1998a) investigates the interaction between inspection-targeting and self-reporting strategies and Seldon et al. (1994) investigate the effect of EPA enforcement funding on private-sector pollution-control investment. They find that each additional dollar on the EPA's enforcement budget generates $2.66–$4.20 of investment across 14 major industrial sectors. Significantly, of course, this tells us nothing about pollution-control performance—purchase of equipment is very different from effective use and maintenance.

Another strand of the literature aims to explain why differing enforcement actions may be taken in different circumstances in terms of political and bureaucratic incentives. These include Wood (1992), Seldon and Terrones (1993), Ringquist (1995), Kleit et al. (1998). Mixon (1994) provides evidence of the public choice determinants of penalties assessed by the EPA for carbon emission violations, showing that while industry lobbying effort has

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25 Spillages from oil tankers have, in fact, received a good deal of econometric attention over many years. Examples include Burrows et al. (1974), Cohen (1986) and, more recently, Viladrich and Groves (1997).

26 An additional strand of the literature attempts to work backwards from observed patterns of enforcement to infer the underlying preferences of Agency's (Helland (1998b) is an excellent example).

only minor effect on the probability of EPA citation for a detected violation, it can impact the *degree* of that citation substantially.[26] This type of result provides an empirical rationale for the ''contestable enforcement'' type models of Kambhu (1989), Nowell and Shogren (1994) and others.

Recalling, briefly, the recent interest in the scope for ''market enforcement'', Badrinath and Bolster (1996) examine stock market reactions to EPA judicial actions on a sample of publicly traded firms between 1972 and 1991.[27] They show that a firm's stock market valuation declines 0.43% in the week of settlement—which for anything but the smallest firm translates into a dollar amount far in excess of the nominal penalty. This implies that the response of financial markets can substantially reinforce fiat penalties, and in so doing bolster the incentive that current shareholders have to ensure that their managers do not transgress. Interestingly, this response is unrelated to violation size, more pronounced for citations under the CAA and greater for more recent citations. Other work on stock market reactions to environmental incidents includes Hamilton (1995) and Laplante and Lanoie (1994).

6. Conclusions and a Research Agenda[28]

It risks banality to say that implementation is an important part of policy-making, yet in many fields economists pay scant attention to issues of enforcement and compliance. An extensive literature—theoretical and empirical—on the enforcement of environmental regulation exists, and the citations here are representative rather than exhaustive.

The basic random monitoring model—familiar from early law and economics—has been developed and enriched in a variety of ways to make it fit with the reality to which it is being applied.

Many things remain on both the theoretical and empirical research agenda, however. Some of the most interesting questions for future research can be (very loosely) grouped as follows:

Industry specific factors: How far can theoretical results derived under particular sets of assumptions, or empirical results from particular enforcement settings, yield general policy implications? What are the context-specific factors to which policy-design must be particularly sensitive? How are changes in market structure, merger activity and so on likely to impact compliance, and how should enforcement strategy be updated to take account of them? Are there particular industries (e.g. those involved in extraction of exhaustible resources) with special features requiring special treatment?

General equilibrium issues: There is a growing recognition—in the business world, as well as among academic economists—that compliance and enforcement variables cannot

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27 Badrinath and Bolster apply the type of event-study analysis applied by Karpoff and Lott (1993) and Borenstein and Zimmerman (1988) in non-environmental settings.

28 An anonymous referee deserves particular thanks for help in developing this section, in particular in identifying many of the items on the proposed research agenda.

be thought about in isolation. Rather, there are linkages between them and a host of other things. What is the relationship between improvements in environmental performance and other aspects of corporate performance?[29] Employees (including managers) may live locally and so be the victims of pollution. How does this alter the firm's agency problem? Would compliance-incentives, then, be enhanced under (perhaps mandatory) profit-sharing? Customers of a firm may also live locally; why and through what channels can they be expected to bring compliance-incentives to bear?

Finance and compliance: There is a rapidly growing literature—referred to earlier in the paper—aiming to assess the role that stock market responses to news of environmental wrongdoing by firms can play as a disciplinary device. There is a lot more potential to study the relationship between financial variables and compliance-performance. Could a more effective penalty structure restrict dividend pay-outs or executive bonuses (recently adopted banking regulations in the US—implementing the FDIC Improvement Act of 1991—have incorporated such restrictions)? If there are lags in penalties for non-compliance, do conventional patterns of managerial turnover and management succession generate incentives to enhance short-run profits at the expense of subsequent penalties? Does control by institutional investors (such as mutual funds or pension funds) exacerbate such an incentive, as those investors can quickly sell their holdings later?[30] What steps might be taken to correct this sort of ''compliance myopia''? More generally, what effect does a firms debt structure have upon compliance incentives? To what extent will firms have incentive to redesign their financial structures strategically, and what can be done about it?

Regulatory failure: What is the appropriate assumption to make about the objectives of enforcement agencies? How can politicians best design institutions to prevent the co-optation or capture of enforcement agents? What role is lobbying likely to play in the development of the enforcement aspects of regulation? Will, for example, firms be likely to lobby for the use of instruments which they anticipate will be easy to evade—and how far will that lobbying be effective? Do special issues arise in the enforcement of transboundary pollutants, and of multinational polluters?

Dynamics: Much (though by no means all) of the research in this field has focussed on static incentives. Considerable scope remains for investigation of the dynamic aspects of the compliance/enforcement problem. To what extent are the lessons of optimal policy derived from static models robust in application to a world in which regulators and firms interact repeatedly through time? What is the linkage between level and pattern of enforcement for product and process innovation, and growth? How can regulatory programs deal with the emergence of new environmental hazards? How much flexibility is optimal, and should old and new hazards be treated equally?

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29 Thus, for example, Gray and Shadbegian (1998) provide empirical evidence that at the plant-level investment in abatement capital tends to crowd-out investment in productive capital. Laplante (1990) points out that improved compliance with environmental regulations may, as a by-product, imply diminished product market competition.

30 Carleton et al. (1998) provide evidence of this sort of short-termism in incentives in a non-pollution setting.

Alternative instruments: There is a current trend in policy-debate to favor ''privatization'' (in one form or another) of the enforcement function—increasing the input of private citizens into the process. How far are such approaches likely to be effective and/or efficient (a) now, (b) in the future?[31] What is the appropriate role for ''third wave'' instruments—either alone or in combination—and should they be considered as substitutes or complements for regulatory implementation? What mechanisms can be developed to incorporate private contributions into the enforcement process (e.g., ''whistle-blower'' programs)? What other potential enforcement instruments might be available? What is the case for further criminalization of environmental damage? How might pro-social behavior be encouraged through non-coercive means (see Harrison 1995)?

Learning from other settings: Enforcement is an issue in many settings other than environmental regulation—criminal law, tax, workplace health and safety, antitrust etc. Most of the theory is common—Harrington's (1988) model of penalty leverage, for example, has antecedents in Greenberg's (1984) work on income tax. Do there remain theoretical insights in those other literatures which remain unincorporated in the environmental enforcement literature? Might implications relevant for our context (such as the way in which individuals and firms respond to different incentives) be drawn from the *empirical* work done in other settings?

Regulations will not work unless they are enforced. Enforcement is where ''the rubber hits the road'' and the most carefully crafted set of regulations is only as good as the enforcement program put in place to implement it. Better understanding the relationship between the enforcement agent and the firm remains, for this reason, a critical part of the research agenda in environmental regulation.

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31 Moving from a system in which government agencies have routinely handled enforcement, to one in which citizens are expected to take a proactive role will, presumably, require a change in behavior amongst private individuals. This could take time and education. Raymond (1999b) provides some interesting empirical analysis of the propensity to complain among citizens in Ontario.

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