PERFORMANCE, PROCESS, AND DESIGN STANDARDS IN ENVIRONMENTAL REGULATION

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Abstract. This papers analyzes efficient regulatory design of a polluting firm who has two kinds of private information about its production environment. First, the firm has better information than the regulator regarding technological possibilities for controlling pollution; and second, some aspects of the firm's implementation of a given technology are potentially unobservable. *Design* standards that specify a particular pollution abatement technology for the firm are efficient when the level of information asymmetry regarding technology choice is low, and when the cost of performance measurement is high; *performance* standards are efficient when the level of penalty needed to induce efficient implementation is unlikely to bankrupt the firm; and *process* standards are efficient when it is not very costly to monitor firm actions. We identify circumstances when each individual regulatory instrument (design, performance, and process standards) alone or in some combination is efficient.

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1. Introduction

Performance incentives (e.g., emissions charges or credits) are widely viewed by economists as an efficient regulatory instrument for achieving a given level of environmental performance by regulated firms. This is particularly true when performance incentives are compared with "command-and-control" types of design standards. Firms typically have better information than regulators concerning the set of feasible strategies to manage environmental performance, and allowing firms to freely act on this information results in socially efficient decisions. As first noted by Weitzman (1974), this simple regulatory prescription can be somewhat altered by allowing information between firms and regulators to be asymmetrically distributed. For example, if firms have better information than regulators about the marginal cost of improving performance, a fixed performance standard may be preferred to performance incentives. However, even in this case, firms are still allowed flexibility in meeting the given performance standard. Indeed, from a purely economic perspective, *design* standards—mandating a particular technological solution to address environmental performance—are viewed as inefficient in virtually all informational and technological environments (e.g., Baumol and Oates, 1975; Antle, 1995).

However, in practice many kinds of environmental and safety regulatory regimes are combinations of performance, design, and process standards.[1,2] This is especially so in food safety regulation where food processors and handlers are required to meet certain measurable food safety standards, where some aspects of firms' production technologies are mandated, and where regulators periodically monitor production activities.[3] Other examples include hazardous waste handling and disposal, and nuclear power generation.

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[1] Performance "standards" are usually accompanied by some form of reward or penalty for performance that meets or falls short of the given standard, and thus might also be called performance "incentives."

[2] As we make more clear below, we use the term "process standard" in reference to regulatory regimes that include some form of monitoring and verification of the *implementation* of a particular technology.

[3] For example, Hazard Analysis Critical Control Point (HACCP) procedures, which are currently mandatory in seafood, meat and poultry, and juice processing industries, combine elements of all three standards. Firms are required to identify food safety hazards and "critical control points," to identify procedures for monitoring critical control points, and to develop systems for record keeping, verification, and testing. Moreover, although firms have responsibility for ensuring the integrity of the HACCP system, regulatory inspectors perform verification activities.

Given that these combinations of instruments are sometimes observed, it is natural to ask why performance incentives that reward or penalize firms based on measured performance are not adequate. Is there something unique about some industrial settings that makes various combinations of instruments efficient, or is regulatory design particularly poor in these sectors?

To answer these questions, we build a model of regulatory design that yields a mix of design, performance, and process standards as an efficient design. Two sorts of plausible informational frictions yield this outcome. First, firms may have better information than regulators regarding the relative cost and efficacy of alternative technologies (e.g., plant modifications, work routines) that affect environmental performance; and second, given that a particular mitigation strategy is identified, many of the day-to-day actions required to implement the strategy may be costly for the regulator to observe. As we will see below, various combinations of design, process, and performance standards can be an efficient response to these sorts of informational asymmetries.

Briefly, performance standards are always preferred when the penalties that can be assessed for poor performance are unconstrained. In particular, if a firm can be made residual claimant for the full social cost of its actions, then there is no inefficiency in its choice of mitigation technology, nor in its implementation of a given technology. In practice, however, firms have limited assets and it may be infeasible to impose the full social cost of an adverse environmental outcome. Limited liability may thus constrain the set of feasible actions and technology choices that can be implemented via regulation. For example, explicit performance incentives may be adequate to induce the "right" technology choice, but insufficient to induce efficient implementation of this technology. In this case, process standards can be used to enforce a particular implementation. Similarly, depending on how well performance can be measured, explicit performance incentives may induce the "wrong" technology choice, but lead to an efficient implementation of the given technology. In this case, imposing a particular design standard (which may not be a first best choice) may be preferable to allowing the firm full flexibility in selecting the technology.

In what follows, we present a formal analysis of these ideas with a model that is loosely based on the principal-agent framework developed by (Prendergast, 2002). The results of our analysis suggest quite plausible circumstances where some form of design standard is efficient, and more generally where various combinations of design, process, and performance standards are efficient. Also, to the best of our knowledge, there has been little recognition of the distinction between *design* (specifying technology) and *process* (monitoring implementation) standards in the environmental regulation literature. As we will see, this distinction plays an important role in our analysis.

2. Model

2.1. **Technology and Preferences.**

A single risk neutral firm controls a production process that results in 'pollution' that for simplicity can be either high or low. Pollution is high with some probability $\pi_i(a) > 0$, where $i = 1, \ldots, n$ indexes an ordering of feasible mitigation technologies with $\pi_i(a) < \pi_j(a)$ for all $i < j$ and $a \in [\underline{a}, \overline{a}]$, and where a represents an action that affects the probability of an adverse outcome. For simplicity we let the units of a be dollars, so that a is also the cost of the action. We assume that higher actions lead to lower probabilities of pollution, and that no action can completely eliminate the possibility of pollution: $\pi_i(a') < \pi_i(a)$ for $a' > a$, and $\pi_i(\overline{a}) > 0$.

When pollution occurs, the firm bears a private cost d, while society bears a cost $D > d$. Assuming the social cost of contamination is larger than the private cost is the simplest possible way of introducing the idea that regulatory control of firm is socially desirable. There are many possible motivations for this assumption. One possibility is that incentives provided by the combination of *ex post* liability and possible damage to the firm's reputation are inadequate for the firm to engage in efficient pollution abatement.

We assume that the firm has finite wealth W, so that the regulator may be constrained in the extent that it can penalize the firm when pollution occurs. We assume that $D > W > d$. The first of these inequalities ensures that performance incentives alone may not suffice to induce efficient actions. The social damages from an adverse outcome are larger than the firm's wealth. The second inequality ensures that the firm will always operate in an unregulated environment.

2.2. **Information.**

We model two types of informational problems faced by the regulator. First, action a can be observed by the regulator only by incurring some cost c_a. Second, the firm is better informed than the regulator about the relative cost and efficacy of alternative technologies. In particular, the firm is fully informed about each technology and the corresponding probability function of an adverse outcome, while the regulator knows only that there are n technologies with probability functions $\{\pi_1(a), ..., \pi_n(a)\}$, but does not know the index that corresponds to each technology. For simplicity, we assume that the regulator assigns equal weight to the probability that any given technology has index i. More precisely, the regulator assigns a probability $1/n$ to the event that technology i has probability function $\pi_j(a)$, where $i, j \in \{1, ..., n\}$.[4] The firm knows with certainty that technology i has probability function $\pi_i(a)$.

Although the regulator does not know probability functions for these n technologies, it does know a technology that is superior to randomly selecting from technologies $\{1, \ldots, n\}$. In particular, we let 0 be the index for this technology, and assume that $\pi_0(a) < \frac{1}{n}\sum_i \pi_i(a)$ for all a. As we will see below, the regulator may wish to specify technology 0 as part of its regulatory design strategy. When it does so, we say that the regulator uses a *design* standard. When the regulator chooses to observe and specify a particular a, we say that the regulator uses a *process* standard. We assume that in the case of a process standard the regulator is informed by the firm about the technology that will be employed to control pollution and the corresponding probability function. We assume that the firm cannot misrepresent this information and the regulator "rubber stamps" the firm's choice of technology.

In practice, the most efficacious technology is unlikely to be also the least costly. Moreover, the firm may have different preferences over the technology choice than the regulator because of different evaluations of the expected benefit from reducing contamination risk. To model this idea, we suppose that a single technology, indexed by $m \in \{1, \ldots, n\}$, offers a benefit b to the firm. Moreover, the firm knows the identity of the technology that yields a private benefit while the regulator does not possess this information. Introducing this benefit adds to our analysis only if m is not the regulator's preferred technology. Thus, we assume that the magnitudes the private benefit b, and probabilities of adverse outcome $\pi_1(a)$ and $\pi_m(a)$ (for given d and D) are such that technology 1 is the full-information or first best technology choice for the regulator, while technology m is chosen in the absence of regulation. Formally, let $a_i(x)$ solve $-\pi_i(a)x = 1$ for all x, and define $\delta_i = 1$ if $i = m$ and 0 otherwise. We make the following assumption:

Assumption 1. *Under full information, technology 1 is preferred by the regulator*

$$1 = \arg\max_i \delta_i b - \pi_i a_1(D) D - a_1(D),$$

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[4] Allowing the regulator to have a more sophisticated prior where, for example, she knows that a particular technology is more likely to have a lower index ("better" probability function for an adverse outcome) than other technologies, would not alter the qualitative properties of our analysis.

and in the absence of regulation technology m *is preferred by the firm*

$$m = \arg\max_i \delta_i b - \pi_i a_m(d)d - a_m(d).$$

The first of part of this assumption provides a baseline for comparison with the various information-constrained regulatory outcomes analyzed below. The second part ensures a divergence of interest between the firm and regulator regarding technology choice. For example, if $b = 0$, there is no conflict of interest in choosing the technology to control pollution and the only concern of the regulator is the choice of the action a taken by the firm. In this case, design standards are never efficient, and the only relevant comparison among regulatory instruments is between performance and process standards (and it will never be efficient to combine these two). Because we are interested in knowing when design standards and combinations of design, performance, and process standards are efficient, we concentrate on the more interesting scenario where the private benefit b is sufficiently large.

The regulator may choose to incur cost c_p to measure pollution and penalize the firm when pollution is high. When the regulator employs such a mechanism we will say that it uses a *performance* standard. This regulatory mechanism is *ex post* in the sense that control by the regulator takes place after pollution outcomes are observed. The first two standards, design and process, are *ex ante* and interim regulations, respectively, since controls and monitoring by the regulator occur before and during the production process.

We have identified three regulatory instruments that may be used to condition the firm's technology and action choices. In the next section, we consider how each of these instruments may complement or substitute, and identify conditions where one or some combination of the instruments represents an efficient regulatory strategy. To do so, we evaluate expected surplus under each strategy and then compare these surplus measures.

2.3. **Regulatory Design.** Under a design standard, the regulator chooses technology 0, and the firm chooses action $a_0(d)$. From the regulator's perspective, the firm receives private benefits b with probability $1/n$ so expected social surplus in this case is given by

$$V_d = b/n - \pi_0(a_0(d))D - a_0(d). \tag{1}$$

With a process standard alone, the firm is free to choose its preferred technology m, but the regulator expends c_a to learn about the technology and to enforce the action $a_m(D)$. Since the firm chooses its preferred technology, the benefit b is obtained for certain. However, *ex ante* (before a technology is chosen by the firm and presented to the regulator for rubber stamping), the regulator does not know the identity of the technology with private benefit to the firm. Thus, in evaluating expected surplus associated with this regulatory instrument, the regulatory assigns the probability $1/n$ to the event $m = i$ for $i \in \{1, \dots, n\}$. Expected social surplus is thus given by

$$V_p = b - \frac{1}{n} \sum_{m=1}^{n} (\pi_m(a_m(D))D + a_m(D)) - c_a. \tag{2}$$

The key difference between performance and design standards is the regulator's ability to monitor the food safety control process. When doing so, the regulator can enforce socially efficient actions conditional on the selected technology. Of course, monitoring of this sort is costly, and in some circumstances the benefits of process control may not be sufficient to cover this cost. The tradeoff between process and design standards also depends on the relative efficacy of the regulator's *ex ante* preferred technology and the firm's preferred technology. Even when the cost of process control is low, imposing a design standards may be efficient if the (expectation of the) firm's preferred technology is substantially inferior. We summarize these results in the following proposition:

Proposition 1. *A process standard is preferred to a design standard when:*

(i) *the cost of process monitoring, c_a, is relatively low;*
(ii) *the social (private) damage D (d) from pollution is large;*
(iii) *the firm's expected technology choice m is not too inferior to the regulator's* ex ante *choice* 0*;*
(iv) *the private benefit b to the firm is large.*

A process and design standard combination is similarly implemented, but now the regulator chooses technology 0 *and* specifies an action that is enforced by incurring cost c_a. In this case, the regulator enforces action $a_0(D)$, and expected surplus is given by

$$V_{pd} = b/n - \pi_0(a_0(D))D - a_0(D) - c_a. \tag{3}$$

This combination of instruments results in the socially efficient action at the regulator's *ex ante* preferred technology, and will be preferred to the design standard alone when the benefit from implementing this action is large relative to the process monitoring cost c_a. A combination of process and design standards will be preferred to a process standard alone when the regulator's preferred technology is substantially superior to the firm's preferred technology. Proposition 2 summarizes these results:

Proposition 2. *Combining process and design standards is preferred to either of these instruments alone when the cost of process monitoring* c_a *is relatively small and, at the same time, when the regulator's preferred technology is substantially superior to the firm's preferred technology.*

In each of the cases considered so far, the regulator does not use explicit performance incentives. When using the design standard alone, the regulator relies on incentives associated with private costs d to induce firm actions that affect food safety. Thus, another possible regulatory instrument includes some form of penalty for poor performance. To use explicit incentives, the regulator incurs a cost c_p to develop the capacity for measuring pollution. As noted earlier, we assume the firm has limited wealth, so the regulator may be constrained in the level of explicit incentives that can be offered.

As noted earlier, the firm (potentially) has two sorts of private information. The firm has better information about the relative efficacy of alternative food safety technologies than does the regulator, and the firm chooses private actions (unless the regulator uses a process standard where actions are observed). In the language of contract theory, the firm has (post contractual) "hidden information" and "hidden actions." Thus, in choosing efficient levels of incentives to offer, the regulator must contend with two different types of incentive constraints. The first of these, which we will sometimes refer to as the "technology" incentive constraint, says that whatever incentives are offered, and conditional on a, the firm will choose the technology that maximizes expected profits. Formally,

$$i = \arg\max_{j} \delta_j b - \pi_j(a)(d+w) - a, \tag{4}$$

where $w \geq 0$ is the penalty associated with observing contamination, and where $\delta_j \in \{0,1\}$ is a random variable from the perspective of the regulator, but that the firm knows for certain. Thus, for example, if w is sufficiently large, the firm may choose to forgo b in order to reduce the probability of an adverse pollution outcome.

The second (potential) incentive constraint says that the firm will choose its action a to maximize private return, conditional on the equilibrium technology selection in (4). Thus, we have

$$a = \arg\max_{\widehat{a}} \delta_i b - \pi_i(a)(d+w) - a. \tag{5}$$

We sometime refer to (5) as the "action" incentive constraint.

In addition the informational constraints in (4) and (5), we suppose that the firm has limited wealth such that w, in combination with private damages d, can be no larger than W. We refer to this as the "limited liability" constraint:

$$w + d \leq W. \tag{6}$$

Performance incentives substitute for design standards. Instead of the regulator choosing its *ex ante* preferred technology, incentives can be used to exploit the firm's private information about the relative merits of the alternative technologies. However, process standards may still have merit because the regulator must deal with multiple incentive issues. In particular, performance incentives relax one incentive constraint (5 above), and allow w to be used entirely for providing incentive to choose the appropriate technology.

If w can be chosen sufficiently large, the regulator can achieve the first best outcome where the firm uses technology 1 and chooses action $a_1(D)$. In this case, performance incentives alone suffice as a regulatory instrument, and will be the preferred instrument so long as the cost of measuring performance, c_p, is sufficiently low. Thus, we have

Proposition 3. *Performance standards are preferred to process and design standards when pollution is easily measured (low c_p), and when the penalty needed to induce efficient technology and action selection is low.*

This outcome is consistent with the 'standard' result regarding the preference of performance incentives (or standards) over design standards. If pollution is easily observed and measured, and if the social damages from are not too high, a simply "pollution charges" system implements the first best technology and action choices. However, as noted in our introduction, in many settings it is actually quite difficult to monitor pollution, and in particular to trace observed pollution levels to individual firms. Moreover, the adverse outcomes associated with some kinds of pollutants (or product "failures") can easily bankrupt the firms that produce them.

If the government is constrained in its choice of w because of the firm's limited liability, performance incentives in combination with process standards, may be an efficient regulatory response. To see this, first consider the use of performance incentives alone, but when the firm's limited liability constraint (6) binds. In this case, $w = W - d$, and constraints (4) and (5) determine the firm's choice of technology and action.

To determine which technology will be selected by the firm, first note that our assumptions on $\pi_i(a)$ imply

$$-\pi_i(a_i(W))W - a_i(W) > -\pi_j(a_j(W))W - a_j(W) \text{ for all } j > i, \tag{7}$$

where $a_i(W)$ and $a_j(W)$ are equilibrium actions obtained from equation (5). Thus, if the firm receives no private benefit from any technology, the solution to (4) is $i = 1$. With private benefit $b > 0$, there will be some technology, say $t \in \{1, .., n\}$, such that

$$\begin{aligned} -\pi_t(a_t(W))W - a_t + b \geq -\pi_1(a_1(W))W - a_1(W) > \\ -\pi_{t+1}(a_{t+1}(W))W - a_{t+1}(W) + b, \end{aligned} \tag{8}$$

where again indexes on actions refer to equilibrium outcomes. When $t = n$, the firm always chooses the technology that yields a private benefit. When $t = 1$, the firm chooses technology 1 irrespective of which technology yields the private benefit. Thus, the magnitude of t provides a measure of 'congruence' between the regulator's and the firm's objectives regarding technology selection. When t is large, the regulator expects the firm to choose a relatively "inefficient" technology. When $t = 1$, the firm's and the regulator's objectives are perfectly aligned (regarding technology selection).

Given our assumed information structure, the regulator knows the value of t, but does not know which of technologies (probability functions) has this index. Thus, as before, the regulatory assigns a probability $1/n$ to event that any given technology has index 1. In what follows, we continue to denote the technology with private benefit by m. If $m > t$, the firm will choose technology 1, while if $m \leq t$, the firm will choose technology m. This yields an expected social surplus

$$V_r = \frac{1}{n}\left(tb - (n-t)[\pi_1(a_1(W))D + a_1(W)] - \sum_{i \leq t}[\pi_i(a_i(W))D + a_i(W)]\right) - c_p. \tag{9}$$

Relative to design and process standards, the benefit from performance incentives comes from use of the firm's knowledge in selecting the technology. Depending on the magnitude of b, and on the incentives that can be offered with w, the firm may select the most efficient technology, unlike the outcomes with design and process standards. However, note that the action which is implemented is determined by the magnitude of W. In particular, since we assume that $D > W$, there is under provision of the action a.

Using a process standard in combination with the performance incentives can overcome inefficiency in action choice.[5] In particular, expected surplus with process and performance standards is identical to V_r, except that we replace t with $s \leq t$, and $a_i(W)$ with $a_i(D)$. Additionally, both the costs c_a and c_p must be incurred to use this combination of instruments.

When compared to design standards, performance incentives lead to a relatively efficient (expected) technology choice. Conditional on the technology, process incentives always result in the efficient action. Thus, performance incentives will tend to dominate design standards when the firm has important private information regarding the appropriate technology, and when the cost of measuring performance is not too high.

We summarize our results regarding performance incentives in the following proposition:

Proposition 4. *Performance incentives dominate design standards when the regulator's* ex ante *efficient technology choice is sufficiently dominated by other technologies, and when the cost of measuring performance is sufficiently low.*

3. Conclusion

This papers analyzes efficient regulatory design of a polluting firm who has two kinds of private information about its production environment. First, the firm has better information than the regulator regarding technological possibilities for controlling pollution; and second, some aspects of the firm's implementation of a given technology are potentially unobservable. *Design* standards that specify a particular pollution abatement technology for the firm are efficient when the level of information asymmetry regarding technology choice is low, and when the cost of performance measurement is high; *performance* standards are efficient when the level of penalty needed to induce efficient implementation is unlikely to bankrupt the firm; and *process* standards are efficient when it is not very costly to monitor firm actions. We identify circumstances when each individual regulatory instrument (design, performance, and process standards) alone or in some combination is efficient.

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[5] In principle, performance incentives can also be used in combination with a design standards, though we choose to leave out formal analysis of this case. Briefly, this combination would lead to inefficient technology choice, and inefficient action choice so long as D is large relative to $W - d$.

References

Antle, J. M. (1995). *Choice and Efficiency in Food Safety Policy.* AEI Press.

Baumol, W. J. and W. E. Oates (1975). *The Theory of Environmental Policy.* Cambridge University Press.

Prendergast, C. (2002). The tenuous trade-off between risk and incentives. *Journal of Political Economy 110*(5), 1071–1102.

Weitzman, M. L. (1974, October). Prices vs. quantities. *Review of Economic Studies XLI*, 477–489.

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