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Setting Standards for Credible Compliance and Law Enforcement*

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Résumé / Abstract

Nous considérons dans cet article la détermination, en information incomplète, de normes légales optimales pour à la fois inciter les citoyens à faire preuve de diligence (prévention) et motiver les agents de la paix à veiller au respect des lois. L'interaction stratégique entre citoyens et agents de la paix détermine l'efficacité des normes choisies. Notre résultat principal est à l'effet qu'un écart entre bénéfices marginaux et coûts marginaux de la diligence est nécessaire afin de réduire les coûts d'application des lois. De plus, les normes peuvent être un substitut aux amendes lorsque les pénalités pour infraction sont fixes. Des amendes maximales peuvent en particulier être contre-indiquées lorsque les normes sont optimalement déterminées.

This paper examines the setting of optimal legal standards to simultaneously induce parties to invest in care and to motivate law enforcers to detect violators of the law. The strategic interaction between care providers and law enforcers determines the degree of efficiency achieved by the standards. Our principal finding is that some divergence between the marginal benefits and marginal costs of providing care is required to control enforcement costs. Further, the setting of standards may effectively substitute for the setting of fines when penalties for violation are fixed. In particular, maximal fines may be welfare reducing when standards are set optimally.

Mots Clés : Normes légales, amendes, respect des lois, comportement stratégique

Keywords : Law Enforcement, Legal Standards, Fines, Strategic Behavior

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1. Introduction

For most parties the threat of being fined or punished provides incentives to take care not to harm others. For instance, motorists may obey traffic regulations, industrial firms may resist fouling the air, and manufacturers may produce safe toys all to avoid fines for violation of standards.

The chance that a party will be fined not only depends on his action, but also on the effort that law enforcers exert to insure compliance. Recent experience reveals that it is difficult for public officials to control the behavior of enforcement agencies.[1] This suggests that law enforcers need to be motivated to detect violators, perhaps by rewarding them according to their success in discovering violations.[2]

In such a setting the equilibrium interaction between potential offenders and law enforcers will determine how regulations are observed and enforced. The amount of effort enforcers exert will depend on the perceived likelihood that parties have violated standards, and the likelihood of violation will depend on how vigorously the law is enforced. In turn the behavior of offenders and enforcers will be shaped by the standards determining if a party has violated the law. Examples of standards include a maximum number of product failures a manufacturer can experience before violating a safety code, or a minimum concentration of effluents found in a water sample that cause a waste discharger to violate emission regulations.

Beginning with Becker (1968) most analyses of the economics of enforcement have taken legal standards as given, and focused on the setting of fines as the primary tool of enforcement. In practice, though, the ability of enforcers to vary statutory fines is restricted by political, moral and legal constraints. In contrast, agencies may have some discretion in setting standards for determining when a party's actions are harmful. The primary goal of this paper is to characterize how the setting of legal standards affects the behavior of complying parties, law enforcers, and the net social surplus generated by the regulation. Another goal of the paper is to examine the extent to which setting standards and fines are substitute

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[1] Most recently displeasure with the performance of the Internal Revenue's Service prompted Congress to cut the agency's compliance budget. Previous to this Congress had similarly intervened in the affairs of the FTC and the EPA to correct what it perceived as inappropriate enforcement of government policy.

[2] This approach differs significantly from most of the formal literature on law enforcement and monitoring, as exemplified by Baron and Besanko (1984), Border and Sobel (1987) and Mookherjee and P'ng (1992, 1994), These analyses assume that law enforcers can commit to a monitoring strategy independent of whether the strategy uncovers violators in equilibrium. A notable exception is Graetz et al (1986) who assume that enforcers are motivated by the fines they collect from prosecuting violators.

instruments for law enforcement.

Under optimal circumstances, where law enforcers can costlessly detect violations, offending parties should be induced to select care so that the marginal cost of care equals the social marginal benefit. However, we find that when enforcers must be incented to monitor compliance, it is desirable to induce care levels that either exceed or fall short of the surplus maximizing level.

The intuition for this finding is that some distortions in care are required to reduce the cost of law enforcement. Suppose standards are initially set so that the marginal costs and benefits from taking care are equated. Then a slight variation in standards will not appreciably affect net benefits,[3] but it will cause a nontrivial adjustment in the enforcer's costs and effort. In some instances a slight loosening of standards will decrease enforcement costs. This will arise whenever looser standards causes enforcers to reduce their effort because the marginal returns from monitoring decrease as the probability of noncompliance decreases. We refer to this as the *complements* case because monitoring effort and standards are complementary inputs in determining the probability of a violation. In this instance, it will be desirable to loosen standards and induce less care in order to reduce the costs of enforcement.

For other applications monitoring effort may fall as the probability of noncompliance increases. This will arise if the returns from monitoring compliance in order to prove a violation will diminish as the degree of noncomplying behavior increases. [4] For this case, referred to as the *substitutes* case it will be desirable to set tighter standards and induce greater care in order to reduce the enforcer's expenditure on effort.

This is the central result of the paper which is formally derived in Section 3. In Section 4 we consider the possibility that the costs of monitoring effort vary by the enforcer's ability to observe and process information. These costs are known privately by the enforcer. We show that the presence of asymmetric information reinforces our main finding that violation standards are distorted to reduce enforcement costs.

In section 5 we examine the possibility that parties differ in the costs they incur in taking care. We show how our main finding generalizes to this case, and demonstrate the optimality of allowing the highest cost parties to pay a fixed fee which absolves them from prosecution for a violation. Further, we demonstrate that

[3] To a first order, a small change in standards has no effect on net benefits since marginal benefits and marginal costs of care are the same.

[4] For instance, it may not be necessary to expend much effort by employing sophisticated measuring devices to detect excessive discharge of effluents when polluters are in obvious violation of the law.

corrupt enforcers can collude with potential offenders to similarly offer high cost parties protection from the law in exchange for a bribe.

In section 6 we examine the relationship between fines and standards. We find that , in contrast to Becker (1968), it is not necessarily desirable to impose the largest fine. Increases in fines may increase costly enforcement effort.

The paper is concluded in section 7 with a summary of results and suggestions for further research. The elements of our model are introduced in the next section and all formal results are derived in the appendix. We relegate the discussion of related findings in the literature to those sections of the paper where the results for comparison with the literature are presented.

2. Elements of the Basic Model

There exists a party who can exert some care denoted by $q > 0$ to avoid harming other individuals. For instance q, may be the discretion a motorist exercises to avoid an accident; q may be the control of emissions by a waste discharger, or q may be product quality a manufacturer supplies to avoid breakdowns. The party incurs a monetary cost or disutility of supplying q, denoted by $C(q)$ which is increasing and strictly convex with $C'(0) = 0$. Social benefits from q are given by Bq, where $B > 0$, is the constant marginal benefit.[5]

The government sets a standard, denoted by s, as a criterion for determining if a party has exercised proper care. Depending on the application, s may be a speed limit which motorists must obey, or a maximum allowable concentration of pollutants in a discharger's water or air sample. To avoid the daunting task of explicitly modeling the bureaucratic and legal process by which violators are prosecuted we adopt a simpler reduced form description of the enforcement process. We assume that given s and q there is a probability that the party will be successfully cited for violating the standard denoted by $\tilde{P}(q,s,e) \in [0,1]$, where e is the effort the law enforcer supplies to monitor the party. We assume that this probability is decreasing as the party supplies more care at an increasing rate with $\tilde{P}_q < 0$, and $\tilde{P}_{qq} > 0$ whenever $e > 0$. A tightening of standards increases the citation probability , $\tilde{P}_s > 0$ for $e > 0$. Further $\tilde{P}$ is increasing in the enforcer's effort, at a decreasing rate so that $\tilde{P}_e > 0$, $\tilde{P}_{ee} < 0$. This implies that the burden of proof falls on the enforcer to demonstrate that a violation has occurred. Finally, we assume that the sign $(\tilde{P}_{es}) = \text{sign}\,(-\tilde{P}_{eq})$ which means that an increase in standards or a decrease in care both have the same

[5] This specification of care benefits is made for simplicity and is not essential for the foregoing analysis.

qualitative effect on the enforcer's marginal returns from effort, $\tilde{P}_e$.[6]

As mentioned in the introduction, we distinguish between two cases describing how an increase in standards affects the incentives for enforcers to monitor. In the *complements* case $d/ds\,(\tilde{P}_e) > 0$, and an increase in standards increases the marginal returns to monitoring. This might arise, for instance, if a party is cited whenever he is simultaneouly violating the law and he is being monitored by the enforcer. In that case a tightening of standards will increase the probability that the party is in fact violating the law, which will therefore increase the enforcer's returns from monitoring. In the *substitutes* case, $d/ds\,(\tilde{P}_e) < 0$, and a tightening of standards reduces the marginal returns to monitoring. This situation arises, for example, if the enforcer knows whether a party has violated the law, but he must expend effort to prove the violation has occurred. When standards are tightened violations of the law are easier to demonstrate. Consequently, the enforcer's expenditure of effort required to prove a violation is reduced.[7]

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[6] A simple specification that satisfies our assumptions is $\tilde{P}\,(q,s,e) = p(\delta,e)$ *where* $\delta = s - q$ measures the gap between the standard and the care provided, and $p_\delta, p_{\delta\delta} > 0$. In the context of pollution standards, δ might measure the difference between acceptable and actual effluent concentration in a water or air sample for example.

[7] An example of a monitoring technology satisfying all the assumptions we have posited for the substitutes case is

$$\tilde{P}\,(q,s,e) = \begin{cases} \int_0^{s-\mu(q)} f(\lambda \mid e)\, d\lambda & s \geq \mu(q) \\ 0 & s < \mu(q) \end{cases}$$

where

$$\begin{aligned} f(\lambda \mid e) &= B(e)e^{-B(e)\lambda} \quad ;\lambda \geq 0 \\ B(e) &= e/(1+e) \\ \mu(q) &= \ln(1+q) \quad ;q > 0 \end{aligned}$$

In this example, an agent exercises care q to produce a product with quality $\mu\,(q)$. The enforcer observes a signal of egality, σ, given by $\sigma = \mu(q) + \lambda$.

Exerting greater effort allows the enforcer to observe quality with greater percision as reflected in the specification for $f(\lambda \mid e)$. One can easily verify that this specification satisfies our assumptions for the substitutes case.

A slight variation on the first example allows us to produce another monitoring technology which satisfies all of our assumptions for the complements case. Here we assume that

$$\sigma = \mu(q) + \{1 - \exp[-(\tilde{\lambda} + g(e)/\mathrm{B}(e))]\}$$

where

$$g(e) = -2\ln\left(\frac{e}{e+1}\right)$$

Then for $s \in (\mu(q) + 1 - e^{g(e)/B(e)},\ \mu(q) + 1)$

If cited the party pays a fine, $F > 0$ for his offense. Consequently, the expected penalty for a violation is given by $P(q,s,e) \equiv F\tilde{P}(q,s,e)$. Throughout most of our analysis we assume that F is fixed, thus allowing us to focus on the setting of standards as the primary tool for shaping compliance and enforcement behavior.[8] Later in section 6 we examine the implications of varying the level of the fines, as well as the extent to which fines and standards are substitute instruments for law enforcement.

Enforcement of the standard is delegated to a single agency, who supplies effort to monitor potential offenders.[9] There is a cost borne by the agency personnel of supplying effort given by the function, *D(e),* which is strictly increasing and convex in effort with $D'(0) = 0$. We make the realistic assumption that it is not possible for public officials to commit the agency to an enforcement policy or to know how diligently the agency enforces standards. Any agency model is likely to be deficient in describing some aspects of bureaucratic behavior, nonetheless we require some paradigm to proceed. We therefore assume that the agency selects an enforcement strategy to maximize the expected sum of fines collected net of the costs of enforcement effort.[10, 11]

The interaction between the party and the enforcer is modeled as a game. The party chooses care *q(e;s)*, given the enforcer's effort and the standard where $q(e;s) = \underset{q}{\text{argmax}} \{U(q,e,s) = -P(q,s,e) - C(q)\}$. The enforcer chooses effort *e(q;s)*

$$\tilde{P}(q,s,e) = \int_0^{\ln[1-(s-\mu(q)] - g(e)/B(e)} f(\lambda \mid e)\, d\lambda$$

which satisfies the assumptions required for the complements case.

[8] This treatment of fines differs from the economics of crime literature, as exemplified by Becker (1968), Stigler (1970), Polinski and Shavell (1979), Malik (1990) Andreoni (1991) and Mookerherjee and P'ng (1992, 1994), which typically treats variations in fines as a primary enforcement tool. In reality the level of fines is set by the legislative branch, and the ability to adjust statutory penalties is restricted as noted by Graetz et al (1986) Harrington (1988) points out that the fines for violation of environmental standards are constrained to be quite small.

[9] We are assuming that economies of scale in collecting and processing information dictate that enforcement be centralized.

[10] This approach is also employed by Graetz et al (1986) in their analysis of tax compliance. Our results do not change significantly if we assume more generally that the agency is rewarded based on some increasing function of the fines collected. For instance, promotion of agency personnel may be conditioned on their success at prosecuting violators.

[11] Alternatively, we might imagine that enforcement is undertaken by a private firm selected by the government. The relative advantages of employing private versus public law enforcement are discussed in Becker and Stigler (1974), Landes and Posner (1975) and Polinski (1980).

given the party's care decision and the standard, where $e(q;s) = \text{argmax}\{\Pi(q,e,s) = P(q,e,s) - D(e) + T\}$. T is a government transfer paid to the agency to insure it breaks even.[12] A Nash equilibrium to this game consists of a decision pair *{q(s), e(s)}* such that *q(s) = q(e(s);s)* and *e(s) = e(q(s);s)*. Below we demonstrate that such an equilibrium exists and that it is unique given *s*.

We assume that the government's objective function, $V = (Bq - T) + U + \lambda\Pi$, is the societal benefit of care net of government subsidies to the enforcer *(Bq-T)*, plus the utility of the party, *U*, plus the enforcer's profit, discounted by $\lambda < 1$. The discounting of enforcer profits derives from the fact that the government's primary constituency is the public at large, including the care providing parties.[13] In this case the government limits the agency's profit to zero. Rewriting V, the government's problem [G-P] becomes

$$\max V(s) = \max B(q(s)) - C(q(s)) - D(e(s)) \qquad \text{[G-P]}$$

The government selects a standard *s* to maximize the net benefit of inducing a given level of care, including the costs of enforcement given the Nash equilibrium behavior of the party and the enforcer.

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[12] Alternatively, T is a tax which allows the government to collect excess revenues when the agency generates positive profits.

[13] In the symmetric information case of section 3 the government sets T = P-D, so that $\Pi = 0$, and the government's objective function simplifies to become Bq-C -D.

3. Analysis of the Simple Case

For a given standard, s, the corresponding Nash equilibrium care level and enforcement effort are characterized by

$$-P_q(q,e,s) - C'(q) = 0 \tag{3.1}$$

$$P_e(q,e,s) - D'(e) = 0 \tag{3.2}$$

Given e, and s, the party selects care to equate the marginal reduction in expected fines to the marginal cost of care. The enforcer optimally responds to q and s by selecting effort to equate the increase in expected fines to the marginal cost of effort. Given our assumptions we have:

Proposition 1: *A unique Nash equilibrium exists satisfying (3.1),(3.2)*

The reaction functions for the party and the enforcer and the resulting Nash equilibrium for the case of complements and substitutes are displayed respectively in Figures 1a and 1b. When the standard and enforcement effort are complements, an increase in care decreases the probability of noncompliance which causes the enforcer to allocate less effort as indicated by the negatively sloped reaction function $e(q{:}s)$ in Figure 1a. A decrease in enforcement effort induces less care as reflected by the positive slope of the $q(e{:}s)$ reaction function. By contrast in the substitutes case, Figure 1b reveals that an increase in care induces greater effort from the enforcer, whereas greater enforcement effort causes the party to be less careful.[14]

The Nash equilibrium characterized by (3.1) and (3.2) corresponds to a given standard, s. To investigate how the equilibrium behavior of the party and enforcer vary with different standard levels we introduce the following assumption

Assumption 1: $(dq/ds)\big|_{de=0} > (dq(e(s),s)/ds)\big|_{de(s)=0}$

Assumption 1 provides sufficient conditions for determining how enforcement effort varies with the tightness of the standards. To interpret this condition, note that $(dq(e(s),s)/ds)\big|_{de(s)=0}$

[14] This result arises because the marginal reduction in expected fines from increasing care is decreased when enforcement effort is increased in the substitutes case.

measures the response of care to an increase in standards required for the enforcer to maintain a constant level of effort. The expression $(dq/ds)\big|_{de=0}$ reflects the actual change in care for an increase in standards undertaken by the party assuming enforcement effort in unchanged. Assumption 1 requires that the actual change in care undertaken by the party is insufficient to maintain the enforcement effort at a constant level. This simply implies that a change in standards will induce a nonzero response from the enforcement agency. Assumption 1 is satisfied for the example where $P(q,e,s) = p(s-q,e)$.[15]

The effect of tightening the standard on equilibrium care and enforcement is characterized by:

Proposition 2: *A tightening of standards always leads to greater care. Given Assumption 1, tighter standards lead to more enforcement effort in the complements case, and it leads to less effort in the substitutes case.*

According to Proposition 2, the party always increases care as standards tighten to partially reduce the probability of being cited. Despite this increase in care, the opportunity for the enforcer to find a violation increases with a tightening of standards. This leads to an increase in effort when standards and effort are complements as the enforcer's marginal return from effort increases. In contrast, when effort and standards are substitutes the enforcer reduces effort since there is less need for monitoring to convict the party.

The government sets a standard to maximize the net benefits from care, including enforcement costs. If enforcement were costless, it would be optimal to set standards to induce care levels which equate the marginal benefit and marginal cost of care. This prescription for setting standards will not be optimal, however, when enforcement is costly. For suppose we begin with such a standard and assume that effort and standards are complements. A small reduction in standards will decrease care, but there will be virtually no effect on net benefits since the marginal benefits and marginal costs of care are approximately equal. However, a small reduction in standards will cause enforcement effort costs to decrease by a non neglible amount. Consequently a small reduction in standards below the level which

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[15] When $P(q,e,s) = P(s-q,e) = P(\delta,e)$, then

$$(dq/ds)\big|_{de=0} = 1 > P_{\delta\delta}/(P_{\delta\delta} + C'') = (dq(e(s),s)/ds)\big|_{de(s)=0}$$

would cause the marginal benefits and costs of care to be equated, will result in an increase in net surplus inclusive of compliance costs. A similar argument establishes that when standards and enforcement effort are substitutes, it is optimal to increase standards above the level which would induce the net benefit maximizing level of care. This is the intuition underlying the following proposition. In that proposition we refer to q^* as the care level which maximizes the net benefits from care (excluding enforcement costs) and $s(q^*)$ as the standard which induces q^* in equilibrium.

> ***Proposition 3:*** *Let $\tilde{s}$ be the solution to [GP]. In the complements case, $\tilde{s} < s(q*)$ and $B - C'(q(\tilde{s})) > 0$ as the optimal standard induces less than the net surplus maximizing level of care. In the substitutes case, $\tilde{s} > s(q*)$ and $B - C'(q(\tilde{s})) < 0$ as the optimal standard induces more than the net surplus maximizing level of care.*

Proposition 3 shows how the enforcement monitoring technology influences the standards for due care, as well as the care level provided in equilibrium. When standards and effort are complements, then standards must be relaxed to prevent enforcers from being overzealous in ensuring compliance. This could possibly explain why some safety and environmental standards appear to be too lax from the view point of the general public. Landes and Posner (1975) have similarly noted that it may be necessary to reduce violation fines to prevent over investment by private enforcers.

The results for the substitutes case are perhaps more surprising. One's intuition might suggest that when enforcement is costly this would add to the costs of inducing parties to take care thus making it optimal to induce lower care. However in the substitutes case, compliance costs are reduced by making it easier for enforcers to convict parties by tightening the standards,but tighter standards induce the parties to supply greater care.

4. Privately Informed Enforcer

In this section we extend our basic model to consider instances in which the enforcer's cost of effort is private knowledge. Such cases may arise when the cost of monitoring varies by the diligence required to apprehend offenders, by the nature of the offense, or by the characteristics of the parties. All of these attributes may be privately known by the enforcement agency. Hidden information may present difficulties for the government, if it operates under a fixed budget, and the agency claims its costs of enforcement are high. The government must insure the agency staff are adequately compensated to insure their participation, but it also must minimize the expenditures required to run the agency. We focus here on how care standards are optimally set under these circumstances.[16]

Suppose that the cost of effort is given by $D(e,\theta)$ where θ is a cost parameter known privately by the enforcer, with the properties that $D_\theta(e,\theta)$, $D_{e\theta}(e,\theta) > 0$ so that total cost and marginal cost of enforcement are increasing in θ.[17] The government is unaware of the realization of θ, but it knows that θ is distributed according to the density $f(\theta) >$ for $\theta \varepsilon [\underline{\theta}, \overline{\theta}]$

We assume that the timing of the interaction between the government , the agency and the party is: first, the agency observes θ. Second, the government offers the agency a menu of contracts $\{T(\theta), s(\theta)\}$, where the dependence of the pair on θ, denotes that it is intended for the agency of type θ.[18] T is a reimbursement paid by the government to the agency to help cover its enforcement expenses. Third, the agency selects a preferred contract. The contract choice is public knowledge and the parties update their beliefs about the type of the enforcer based on the agency's contract choice. Fourth, simultaneously the parties choose their level of care, and the agency selects enforcement effort. Finally the agency collects fines from those parties found to be in violation of the standard.

Let $\Pi(\theta'|\theta)$ denote the agency's expected profit who selects the contract $\{T(\theta'), s(\theta')\}$ when their type is θ, where

$$\Pi(\theta'|\theta) = P(q(s(\theta'),\theta'), e(s(\theta'),\theta), s(\theta')) - D(e(s(\theta'),\theta),\theta) - T((\theta'))$$

$q(s(\theta'),\theta')$ is the equilibrium care level for the standard $s(\theta')$ given that the enforcer has chosen the contract intended for type θ'. The enforcer's contract choice affects the parties' beliefs about the enforcer which influences their choice of care. The equilibrium enforcement effort $e(s(\theta'),\theta)$ depends on the standard, as well as on θ which is the enforcer's type.

The government's problem [GP-A] for this case is to choose $\{T(\theta), s(\theta)\}$ to

$$\max E_\theta \; \hat{V}(s(\theta),\theta)) \qquad \text{[GP-A]}$$

where E_θ is the expectation taken with respect to θ, and such that for all $\theta \varepsilon [\underline{\theta}, \overline{\theta}]$: (i) the agency breaks even , $\Pi(\theta) \equiv \Pi(\theta|\theta) \geq 0$, (ii) the party picks the contract

[16] To our knowledge the impact of privately informed enforcers on the design of optimal fines and standards has not been analyzed in the literature.

[17] We continue to assume that D is increasing and strictly convex in e, and that $D_e(0,\theta) = 0$.

[18] That is, the menu is designed so that type θ will choose $\{T(\theta), s(\theta)\}$

which is intended for it, $\Pi(\theta|\theta) \geq \Pi(\theta'|\theta)$.

In what follows, we focus on the separating equilibria solution to [GP-A] in which each type θ is induced to select a separate contract.[19] As a convenient benchmark for this solution to [GP-A] consider the complete information case, analyzed in section 3 , where the government and the party know the agency's cost parameter, θ, at the time of contracting. Let $s^*(\theta)$ be the standard which induces the party to choose the net benefit maximizing care, q^*, in equilibrium. Refer to $\tilde{s}(\theta)$ as the optimal standard given the agency is known to be of type θ. We then have:

> ***Proposition 4:*** *In the separating solution to [GP-A] the optimal standard,* $\hat{s}(\theta)$ *satisfies (i)* $\hat{s}(\theta) \leq \tilde{s}(\theta) \leq s^*(\theta)$ *for the complements case, and (ii)* $\hat{s}(\theta) \geq \tilde{s}(\theta) \geq s^*(\theta)$ *for the substitutes case (with strict inequality for* $\theta > \underline{\theta}$ *in both cases) .*

The presence of a privately informed agency causes a greater distortion in standards away from $s^*(\theta)$,the level which induces the net benefit maximizing care. This arises because the agency will try to overstate its costs to obtain a more favorable contract from the government. In the case of complements the government reacts by reducing compliance standards which decreases the enforcer's effort. This renders it less attractive for a low cost enforcer to claim to be high cost, by reducing the number of effort units over which he can exercise his cost advantage. As a result of the reduction in standards the party provides less care as $q(\hat{s}(\theta)) < q(\tilde{s}(\theta)) < q^*$

When effort and care are substitutes the government increases the standards, thus reducing the incentives for the enforcer to monitor. Again this makes it less attractive for a low cost enforcer to pretend to be high cost, because it reduces the number of effort units over which he may exercise his cost advantage. This tightening of standards induces the party to increase its care as $q(\hat{s}(\theta)) > q(\tilde{s}(\theta)) > q^*$.

5. Heterogenous Parties

In this section we examine desired alterations in optimal standards when

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[19] Another possible policy for the government is to offer pooling or semi-pooling contracts in which several different types of enforcers are induced to accept the same contract. In this case, the enforcer's choice of a contract would not necessarily reveal his type. Such a policy might be beneficial if it were less costly to enforce standards when the enforcer's type was not known by the care providers. Deriving conditions under which pooling or separating contracts are preferred seems quite difficult, and therefore determining the optimal form of contract remains an open question. Although we focus on separating contracts in our discussion, we demonstrate in the appendix that Proposition 4 also holds for the case of pooling contracts.

there is a heterogenous population of parties varying according to their cost of taking care. Variations in cost arise because the parties have access to different methods to reduce the harmful effects of their behavior.[20] Further we assume that the parties are privately informed about their cost of taking care. As in the previous cases we've studied, the government sets a uniform standard which parties must adhere to. However, with a heterogenous population, the government may grant higher cost parties immunity from the standard, if they pay a fix fee.[21] This arrangement saves high cost parties the expense of meeting standards, while reducing the enforcer's monitoring costs.[22]

We model the heterogenous party population by assuming that an individual's cost of care is given by $C(q,\mu)$, where μ is a privately observed cost parameter. Total and marginal costs are increasing in μ, *with*, $C_{\mu}, C_{\mu q} > 0$, for $q > 0$.[23] The density of parties of type μ in the population, which is normalized to one is given by $g(\mu) > 0$ for $\mu\, \varepsilon\, [\underline{\mu}, \overline{\mu}]$.

We assume the government offers parties the choice of either paying a fixed assessment, A to the enforcer, which exempts them from being cited, or the choice of trying to meet the standard, s. Let $q(s,\mu) = \text{argmax}(-P(e(s),q(s),s) - C(q,\mu))$, be party type μ's optimal care to avoid being fined. Given A, and q, type μ's response is to pay A and avoid providing care if $(-P(q(s,\mu)e(s),s) - C(q(s,\mu),\mu)) \leq -A$, otherwise the party provides care $q(s,\mu)$. For a given A, some subset of the highest cost individuals $\mu\, \varepsilon\, (\hat{\mu}, \overline{\mu}]$ for $\hat{\mu} < \overline{\mu}$ will elect to pay the assessment, A. The cutoff type, $\hat{\mu}$ will just be indifferent between investing in care and paying the assessment to avoid being cited.

The government's problem, for the case of heterogenous parties, [GP-P] is to choose the assessment A to

$$\max\ E_{\mu < \hat{\mu}} \{Bq(s,\mu) - C(q(\mu,s),\mu)\} - D(F(\hat{\mu})e(s)) \qquad \text{[GP-P]}$$

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[20] For instance, firms may differ according to the costs they incur to reduce pollution.

[21] Alternatively, parties may self report their violations to the agency, where upon they are assessed a fixed fee. as in Kaplow and Shavell (1994).

[22] In theory if the set of potential offenders was known by the government, a menu of different standards and fines could be offered to separate out offenders by their cost of taking care. This approach is employed by Mookherjee and P'ng(1994) in their analysis of marginal deterrence of crime. Such fine tuning of standards is impractical however when the identity of the offenders is unknown at the time standards are determined.

[23] We continue to assume that C is increasing and strictly convex in q with $C_q(0,\mu) = 0$.

The maximand in [GP-P] represents the expected net benefit of care minus the enforcement costs taken over the population of parties investing in positive care levels. Those parties $\mu > \hat{\mu}$ who exempt themselves, contribute zero net benefits and impose zero enforcement costs on society. The solution to [GP-P] is characterized in the following proposition. In that proposition we refer to $\tilde{s}$ as the optimal standard, and s^* as the standard that maximizes $E_{\mu<\hat{\mu}}\{Bq(s,\mu) - C(q(s,\mu),\mu)\}$

> ***Proposition 5:*** *In the solution to [GP-P] (i) no parties are exempted from standards when B is sufficiently large, (ii) when exemption occurs* $A < F$, *and* $\hat{\mu}$ *satisfies* $v(\hat{\mu}) = Bq(\tilde{s},\hat{\mu}) - C(q(\tilde{s},\hat{\mu}),\hat{\mu}) - D'(F(\hat{\mu})e(\tilde{s}))e(\tilde{s}) = 0$ *(iii)* $\tilde{s} < s^*$ *for the case of complements, and (iv)* $\tilde{s} > s^*$ *for the case of substitutes.*

Part (i) of Proposition 5 indicates that parties are exempted only if the benefits from taking care are sufficiently small, otherwise even high cost care providers are induced to provide care. Part (ii) indicates when exemption arises that higher cost parties opt to pay the assessment rather than risk paying a higher fine if they are cited. The assessment is set at a level so that only those parties with a negative care contribution to social welfare , net of marginal enforcement costs, $v(\mu)$, seek exemption. Parts (iii) and (iv) verify that the same distortion in standards arises when parties are heterogenous as when they are homogenous.

When exemptions are possible, dishonest enforcers may also take bribes from parties not wanting to provide care. To analyze this possibility, suppose for now that government sanctioned exemptions are not offered, perhaps because the benefits from care are too large. Imagine that the enforcer offers any party an exemption from being monitored if the party pays the enforcer a bribe equal to *Y*. Assume also that such illegal activity goes unnoticed by the government, and that agreements between parties and the enforcer are kept.[24] Given the standard, *s*, the enforcer's problem , [EP] is to set the level of the bribe, *Y* and enforcement effort *e(s)* to

$$\max\ E_{\mu<\mu'}\{P(q(s,\mu),e,s)\} - D(F(\mu')e) + (1-F(\mu'))\,Y + T \qquad \text{[EU]}$$

where all parties $\mu \,\varepsilon\, (\mu', \bar{\mu}]$ pay the bribe and type μ' is indifferent to paying the

[24] One rationale for why corrupt agents may trust one another to honor agreements is that they may want to maintain a reputation for being reliable. See Tirole (1992) for one approach to modeling collusion between corrupt individuals.

bribe and investing in care. The solution to the enforcer's problem is characterized in

> ***Proposition 6:*** *In the solution to [EP], (i) the enforcer always offers a bribe $Y < F$ which the higher cost parties $\mu \varepsilon (\mu', \bar{\mu}]$ pay. (ii) Y satisfies*

$$(1 - F(\mu') - Y(d\mu'/dY)f(\mu')) = -\{P(q(s,\mu'),e(s),s) - D'(F(\mu')e(s))e(s)\}(d\mu'/dY)f(\mu')$$

According to Proposition 6 the enforcer always offers a bribe which some non negligible subset of the higher cost parties agree to pay for exempting themselves from being cited. The optimal bribe, characterized by the equality in (ii) sets the enforcer's marginal revenue from an increase in the bribe to the marginal increase in the collection of fines as more types invest in care in response to an increase in the bribe.

Propositions 5 and 6 suggest that if illegal bribes cannot be detected, high cost parties will always exempt themselves from fines by paying the enforcer a fee. In cases where the benefits from care are large, the fee will be a bribe paid to the enforcer, as assessments for exemptions will not be sanctioned by the government. In cases where the benefits from care are small, the fee may be a government sanctioned assessment, if A is less than Y.[25]

6. Setting Optimal Fines

To this point in our analysis we have assumed the level of fine for a violation, F, is fixed exogenously. Here we investigate whether increases in F are welfare improving. Becker (1968) first observed that larger fines deter parties from breaking the law and thus reduce enforcement effort required to insure compliance. As we demonstrate, this argument may fail to apply when the enforcer's effort supply depends on the probability that the party is in compliance.[26]

Suppose the fine, F, is increased. This will cause the government to adjust

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[25] We conjecture that A will be less than Y for B sufficiently small, although we have so far been unable to verify this.

[26] Several analyses have discovered reasons why maximal fines may be not be desired. Malik (1990) demonstrates that increasing fines may increase agent's avoidance behavior, thus leading to higher enforcement costs. Andreoni (1992) argues that juries are less apt to convict offenders when fines are more severe. thus reducing the deterrence power of maximal fines. Polinski and Shavell (1979) argue that maximal fines are welfare decreasing in that some offenses should not be deterred if marginal benefits of the crime exceed the marginal costs. Stigler (1970) and Mookherjee and P'ng (1994) show that fines should be varied continuously in order to maintain marginal deterrence in enforcement.

its optimal standard, $\tilde{s}$, and it will induce both the party and the enforcer to adjust their behavior. Let de/dF and dq/dF represent respectively the rate of change in equilibrium enforcement effort and care as F is increased. Then the increase in welfare from a change in F can be written as

$$dV/dF = (B-C_q)(dq/dF) - D_e(de/dF)$$

$$= \{(B-C_q)/D_e - (de/dF)/(dq/dF)\}D_e\,(dq/dF)$$

$$\begin{pmatrix} > \\ = \\ < \end{pmatrix} 0 \;\; as\, (de/ds)/(dq/ds) \;\; \begin{pmatrix} > \\ = \\ < \end{pmatrix} \;\; (de/dF)\,/dq/dF) \qquad (6.1)$$

where the first line of (6.1) follows from the Envelope Theorem, the second line follows from the first by rearranging terms and the last line follows from the condition for setting optimal standards, $(dV/ds = 0)$.[27]

A necessary and sufficient condition for ordering $(de/ds)/(dq/ds)$ and $(de/dF)/(dq/dF)$ and thus determining whether increasing fines is welfare enhancing is given in

Proposition 7:

$$(de/ds)/(dq/ds) \begin{pmatrix} > \\ = \\ < \end{pmatrix} (de/dF)/(dq/dF) \;\; as \;\; d/ds\ \{-P_e/P_q\} \begin{pmatrix} > \\ = \\ < \end{pmatrix} 0.$$

To interpret (6.1) note that under the optimal standard $(de/ds)/(dq/ds)$ represents the rate at which enforcement effort and care may vary while keeping total surplus constant. In the complements case, too little care is allocated. An increase in F will induce the party to provide more care, but it will also cause the enforcer to expend more effort. If the rate at which extra effort expended for an increase in care is sufficiently small (less than $(de/ds)/(dq/ds)$) then increasing the fine will increase welfare. Otherwise increasing the fine will reduce welfare, if it will induce too much enforcement effort to be expended. A similar argument serves to confirm this intuition for the case of substitutes.

Proposition 7 provides necessary and sufficient conditions for an increase in the fine to be welfare decreasing. It's easy to verify that in the substitutes case where $P_{es} < 0$, that $d/ds\{-P_e/P_q\} < 0$. This implies that a small increase in the violation fine is welfare decreasing and it provides an interesting exception to Becker's argument for maximal fines. The intuition supporting this finding is that in the substitutes case, the level of care induced is excessive in order to limit

[27] The optimal standard satisfies dV/ds = 0 or $B-C_q)/D_e = (de/ds)/(dq/ds)$.

enforcement effort. (see Proposition 3) An increase in the fine reduces welfare, by causing parties to further increase care which also induces enforcers to expend more effort.

7. Conclusion

Our analysis offers one rationale for the divergence between the marginal benefits and the marginal costs from taking care which often arise in practice. Pollution and safety standards may either be set too loose or too stringent to discourage enforcers from exerting excess effort. Whether standards are set too low or too high depends on the available technology for identifying violators.

Our analysis also reveals the importance of setting standards, not only to influence compliance, but also to shape the behavior of enforcers. In circumstances where penalties are fixed, varying standards may be one of the few tools policy makers have to affect compliance and reduce enforcement expenses. In instances where fines can be varied as well, it may be counterproductive to set maximal fines which encourage overzealous law enforcement.

Appendix

Proof of Proposition 1

The assumptions on $P(q,e,s)$ and on $C(q)$ and $D(e)$ suffice to insure $U(q,e,s)$ is strictly concave in q and $\Pi(q,e,s)$ is strictly concave in e. If we further require that $q,e \leq \mu < \infty$ then by Theorem 3.1 of Friedman (1990), a pure strategy Nash equilibrium exists. The conditions on $P(q,e,s)$, $C(q)$ and $D(e)$ further insure that the Nash equilibium is interior (with $e,q > 0$) and that it is characterized by the first order conditions (3.1) and (3.2) in the text. Finally, uniqueness of equilibrium follows by verifying that the reaction function of the party and of the enforcer are continuous and have slopes of opposite signs indicating a unique equilibrium at the single point of intersection. ■

Proof of Proposition 2

Totally differentiating eqs. (3.1) and (3.2) in the text with respect to s yields the following:

$$\begin{pmatrix} -P_{qq}-C_{qq} & -P_{qe} \\ P_{qe} & P_{ee}-D_{ee} \end{pmatrix} \begin{pmatrix} dq/ds \\ de/ds \end{pmatrix} = \begin{pmatrix} P_{qs} \\ -P_{es} \end{pmatrix} \qquad \text{(A2.1)}$$

Cramer's rule applied to (A2.1) implies:

$$\frac{dq}{ds} = \frac{P_{qs}\,(P_{ee}-D_{ee}) - P_{qe}P_{es}}{\Delta} > 0 \qquad \text{(A2.2)}$$

$$\frac{de}{ds} = \frac{(P_{qq} + C_{qq})\,P_{es} - P_{eq}\,P_{qs}}{\Delta} \gtrless 0 \ \ as\ P_{qe} \gtrless 0 \qquad \text{(A2.3)}$$

where $\Delta = (P_{qq} - C_{qq})\,(P_{ee} - D_{ee}) + P_{qe}^2 > 0$. The sign of dq/ds follows immediately from our assumptions about P and D. To verify the sign of de/ds, rewrite (A2.3) so that

$$\frac{de}{ds} = \left\{ \frac{P_{se}}{P_{qe}} - \frac{P_{qs}}{(P_{qq} + C_{qq})} \right\} \frac{(P_{qq} + C_{qq})\,P_{qe}}{\Delta} \qquad \text{(A2.4)}$$

$$= \left\{ \frac{dq}{ds}\Big|_{de=0} - \frac{dq(e(s),s)}{ds}\Big|_{de(s)=0} \right\} \frac{(P_{qq} + C_{qq})\,P_{qe}}{\Delta}$$

$$\gtrless 0 \;\; as \;\; P_{qe} \gtrless 0 \Leftrightarrow P_{se} \lessgtr 0$$ by Assumption 1. ■

Proof of Proposition 3

The optimal standard $\tilde{s}$ satisfies

$$\frac{dV}{d\tilde{s}} = (B - C_q)\frac{dq}{ds} - D_e \frac{de}{ds} \;\; 0 \tag{A3.1}$$

Solving for $(B - C_q)$ from (A3.1) yields

$$B - C_q = \frac{D_e \dfrac{de}{ds}}{\dfrac{dq}{ds}} \tag{A3.2}$$

It follows from (A3.2) and Proposition 2 that

$$B - C_q \gtrless 0 \;\; as \;\; \frac{de}{ds} \gtrless 0 \Leftrightarrow P_{se} \gtrless 0 \tag{A3.3}$$

Finally, since $C_{qq} < 0$, and q is increasing in s, it follows from (A3.3) that

$$\tilde{s} \gtrless s^* \;\; as \;\; P_{se} \gtrless 0 \;\; ■ \tag{A3.4}$$

Proof of Proposition 4

First we provide necessary and sufficient conditions for satisfying the conditions (i) and (ii) of [GP-A] in the text. Applying routine arguments (see Guesnerie and Laffont (1984)) one can readily show that the schedules $\{T(\theta), s(\theta)\}$ are differentiable almost everywhere, and that the effort level induced, $e(s(\theta'), \theta)$ must be non-increasing in θ' where $\theta' = \theta$. Further,

$$\begin{aligned} \Pi'(\theta) &= \Pi_1(\theta' \mid \theta)\Big|_{\theta'=\theta} \frac{d\theta'}{d\theta} + \Pi_2(\theta' \mid \theta)\Big|_{\theta'=\theta} \\ &= -D_\theta\,(e(s(\theta),\theta),\theta) \end{aligned} \tag{A4.1}$$

where the second line of (A4.1) follows from the Envelope Theorem. Since $\Pi(\theta)$ is decreasing, part (i) is insured provided

$$\Pi(\bar{\theta}) = 0 \tag{A4.2}$$

Combining (A4.1) - (A4.2) parts (i) and (ii) of [GP-A] are satisfied provided,

$$\Pi(\theta) = \int_{\theta}^{\bar{\theta}} - D_\theta\,(e(s(\tilde{\theta}),\tilde{\theta}),\tilde{\theta})\,d\tilde{\theta} \tag{A4.3}$$

Substituting for $\Pi(\theta)$ from (A4.3) into [GP-A], integrating by parts and rearranging terms yields

$$\max_{s(\theta)} E_\theta \hat{V}(s(\theta),\theta) = \max_{s(\theta)} E_\theta \left\{ B_q(\cdot) - C(q(\cdot)) - D(e(\cdot),\theta) - (1-\lambda) D_\theta(e(\cdot),\theta)) \frac{F(\theta)}{f(\theta)} \right\} \tag{A4.4}$$

where we have deleted the arguments of $q(\cdot)$ *and* $e(\cdot)$ for notational convenience. Rewriting $\hat{V}(s(\theta),\theta)$ in terms of $V(s(\theta),\theta) \equiv B_q(\cdot) - C(q(\cdot)) - D(e(\cdot),\theta)$ and recognizing that D_θ is implicitly a function of $s(\theta)$ and θ we have

$$\hat{V}(s(\theta),\theta) = V(s(\theta),\theta) - (1-\lambda) D_\theta(s(\theta),\theta) \frac{F(\theta)}{f(\theta)} \tag{A4.5}$$

Assuming a separating solution to [GP-A], Let

$$\hat{s}(\theta) = \underset{s(\theta)}{argmax}\ \hat{V}(s(\theta),\theta)$$

$$\hat{s}(\theta) = \underset{s(\theta)}{argmax}\ V(s(\theta),\theta)$$

Then, employing standard revealed preference arguments for all $\theta \in [\underline{\theta},\overline{\theta}]$

$$\hat{V}(\hat{s}(\theta),\theta) \geq \hat{V}(\tilde{s}(\theta),\theta) \tag{A4.6}$$

$$V(\tilde{s}(\theta),\theta) \geq V(\hat{s}(\theta),\theta) \tag{A4.7}$$

with strict inequality for $\theta > \underline{\theta}$. Adding (A4.6) and (A4.7) and simplifying yields

$$(1-\lambda)[D_\theta(\tilde{s}(\theta),\theta) - D_\theta(\hat{s}(\theta),\theta)] \geq 0 \tag{A4.8}$$

This implies, since $1-\lambda > 0$ that

$$\tilde{s}(\theta) \gtreqless \hat{s}(\theta) \ \ as\ \ \frac{d}{ds(\theta)} D_\theta(s(\theta),\theta) \gtreqless 0 \tag{A4.9}$$

But

$$\frac{d}{ds(\theta)} D_\theta(s(\theta),\theta) = D_{\theta e}\frac{de}{ds} \tag{A4.10}$$

$$\underset{=}{\text{s}}\ \frac{de}{ds} \gtrless 0 \ \ as\ \ P_{sq} \gtrless 0$$

where the second line of (A4.10) follows from Proposition 2. Collecting (A4.9) and

(A4.10) we have

$$\hat{s}(\theta) \leq \tilde{s}(\theta) < s^* \quad for \quad P_{sq} > 0 \tag{A4.11}$$

$$\hat{s}(\theta) \geq \tilde{s}(\theta) > s^* \quad for \quad P_{sq} < 0 \tag{A4.12}$$

with strict inequality for $\theta > \underline{\theta}$, thus proving Proposition 4. ■

Proof of Proposition 5

The solution to [GP-P] as posed in the text is characterized by the first order conditions

$$E_{\mu \leq \hat{\mu}} [B - C_q(q(\mu,s),\mu)] \frac{dq(\cdot)}{ds} - D'(F(\hat{\mu})e(s)) \frac{de}{ds} = 0 \tag{A5.1}$$

$$\hat{V}(\hat{\mu}) \equiv B_{q(\hat{\mu},s)} - C(q(\hat{\mu},s),\hat{\mu}) - D'(F(\hat{\mu})\, e(s))e(s) \geq 0 \quad (= if\ \hat{\mu} < \overline{\mu}) \tag{A5.2}$$

where (A5.1) and (A5.2) correspond respectively to the maximization of [GP-P] with respect to s and $\hat{\mu}$. The Nash equilibrium care and enforcement levels, $q(\mu,s)$ *and* $e(s)$ are characterized by

$$-P_q(q(\mu,s),e(s),s) - C_q(q(\mu,s),\mu) = 0; \; \mu \leq \hat{\mu} \tag{A5.3}$$

$$E_{\mu\leq\hat{\mu}} P_e(q(\mu,s),e(s),s) - D'(F(\hat{\mu})e(s))F(\hat{\mu}) = 0 \tag{A5.4}$$

First we prove parts (iii) and (iv) of the Proposition. Differentiating (A5.3) and (A5.4) totally w.r.t. s yields:

$$-P_{qq}\left(\frac{dq}{ds}\right) - P_{qe}\left(\frac{de}{ds}\right) - P_{qs} - C_{qq}\left(\frac{dq}{ds}\right) = 0; \quad \mu \leq \hat{\mu} \tag{A5.5}$$

$$E_{\mu \leq \hat{\mu}}\left\{P_{eq}\left(\frac{dq}{ds}\right) + P_{ee}\left(\frac{de}{ds}\right) + P_{es}\right\} - D'' F(\hat{\mu})\left(\frac{de}{ds}\right) = 0 \tag{A5.6}$$

Combining (A5.5) and (A5.6) one obtains

$$\frac{de}{ds} = \frac{A}{B} \tag{A5.7}$$

where

$$A \;=\; -E_{\mu\,\leq\,\hat{\mu}}\left\{\frac{-P_{qs}}{P_{qq}+C_{qq}} \;+\; \frac{P_{es}}{P_{qe}}\right\} P_{eq} \qquad \text{(A5.8)}$$

$$B \;=\; E_{\mu\,\leq\,\hat{\mu}}\left\{\frac{-P_{qe}{}^{2}}{P_{qq}\;+\;C_{qq}} \;+\; P_{ee}\right\} \;-\; D^{\prime\prime}\,F(\hat{\mu}) \;<\; 0 \qquad \text{(A5.9)}$$

It follows from Assumption 1 and (A5.7) - (A5.9) that

$$\frac{de}{ds} \gtrless 0 \;\; as \;\; P_{qe} \gtrless 0 \;\Leftrightarrow\; P_{qs} \gtrless 0 \qquad \text{(A5.10)}$$

In addition (A5.5) and (A5.6) also imply that

$$\frac{dq\,(\mu,s)}{ds} \;=\; -\;\frac{P_{qe}\left(\dfrac{de}{ds}\right) \;+\; P_{qs}}{(P_{qq}\;+\;C_{qq})} > 0 \qquad \text{(A.5.11)}$$

where the inequality follows from (A5.10). Substituting (A5.10) and (A5.11) into the first order condition for s, (A5.4) allows one to verify parts (iii) and (iv) of Proposition 5.

To verify part (i), notice that for B sufficiently large $V(\hat{\mu})$ is strictly positive for all $\hat{\mu}$, as both terms $C(q(\hat{\mu},s),\hat{\mu})$ and $D^{\prime}(\cdot)\,e(s)$ in (A5.2) are bounded above since $q\,(\mu,s)$ and $e\,(s)$ are bounded, while the term $B\,q(\hat{\mu},s)$ is arbitrarily large. Hence, $\hat{\mu} \;=\; \bar{\mu}$ and no party types are exempted when the marginal benefits of care are sufficiently large.

To verify part (ii), notice that for a type which decides to exempt himself

$$-A \;\geq\; \min_{q}\;(-p\,(q,e\,(s),s) \;-\; C(q,\mu)) \;>\; -F \qquad \text{(A5.12)}$$

or A < F. This completes the proof of Proposition 5. ■

Proof of Proposition 6

Given s, the first order condition for Y in the solution to the enforcer's problem, [EP] stated in the text is

$$(P\,(q\,(\mu^{\prime},s),e\,(s),s) \;-\; D^{\prime}(F\,(\mu^{\prime})e\,(s))\,e\,(s) \;-\; Y)f\,(\mu^{\prime})\left(\frac{d\mu^{\prime}}{dY}\right) \;+\; (1 \;-\; F(\mu^{\prime})) \;\geq\; 0 \qquad \text{(A6.1)}$$

$$(\;=\; if \;\; \mu^{\prime} \;<\; \bar{\mu})$$

Notice that when $\mu' = \bar{\mu}$

$$Y = P(q(\bar{\mu},s),e(s),s) + C(q(\bar{\mu},s),\bar{\mu}) \tag{A6.2}$$

Substituting for this value of Y in (A6.1) reveals that $\mu' = \bar{\mu}$ can not be a solution to [EP]. Therefore, $\mu' < \bar{\mu}$.

Rearranging (A6.1) and noting that it holds with equality yields the expression appearing in Proposition 6. Finally, the result that Y < F follows from noting that

$$-Y \geq \min_q \left(-p(q,e(s),s) - C(q,\mu)\right) > -F \tag{A6.3}$$

for all $\mu \leq \bar{\mu}$. ■

Proof of Proposition 7

According to eq (6.1) in the text

$$\frac{dV}{dF} \gtreqless 0 \quad as \quad \frac{de/ds}{dq/ds} \gtreqless \frac{de/dF}{dq/dF}$$

The expressions for $\frac{de/ds}{dq/ds}$ *and* $\frac{de/dF}{dq/dF}$ are given by

$$\frac{de/d\alpha}{dq/d\alpha} = \frac{(\lambda_\alpha + P_{eq})\,\Delta_q\,(P_{qe}^2 - P_{ee}\,\Delta q)}{(P_{qe}^2 - P_{ee}\Delta_q)^2 + (P_{qe}^2 - P_{ee}\,\Delta_q)(\lambda_\alpha + P_{eq})}\;;\;\alpha = S,F \tag{A7.1}$$

where

$$\lambda_F = -\frac{P_e}{P_q}\,\Delta_q > 0 \tag{A7.2}$$

$$\lambda_s = -\frac{P_{es}}{P_{eq}}\,\Delta_q > 0 \tag{A7.3}$$

$$\Delta_q = P_{qq} - C_{qq} > 0 \tag{A7.4}$$

It is easy to demonstrate that the RHS of (A7.1) is increasing in λ_α so that

$$
\begin{aligned}
\frac{de/ds}{dq/ds} \gtreqless \frac{de/dF}{dq/dF} &\Leftrightarrow \lambda_S \gtreqless \lambda_F \\
&\Leftrightarrow -\frac{P_{es}}{P_{eq}} \gtreqless -\frac{P_e}{P_q} \\
&\Leftrightarrow \frac{d}{ds}\left(-\frac{P_e}{P_q}\right) \gtreqless 0
\end{aligned}
\tag{A7.5}
$$

where one can easily verify the last equivalence in (A7.5). ■

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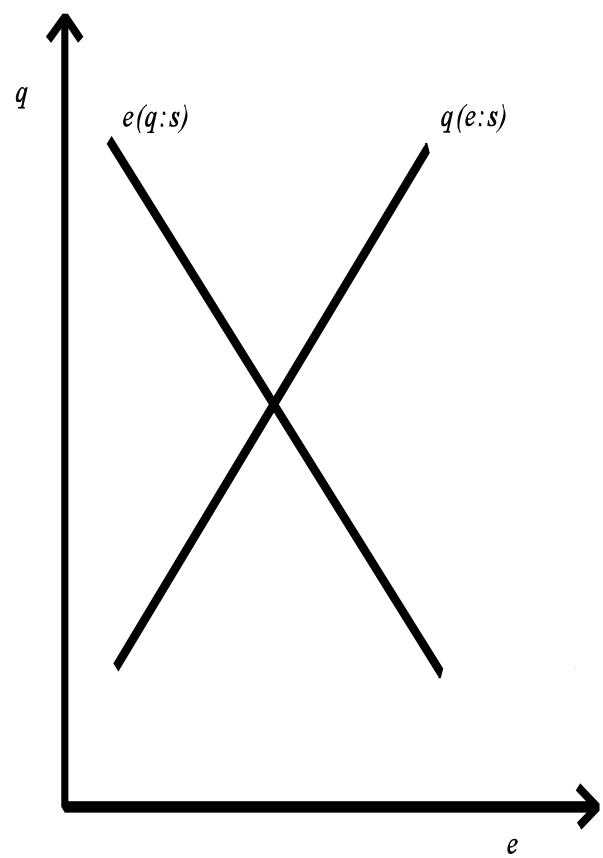
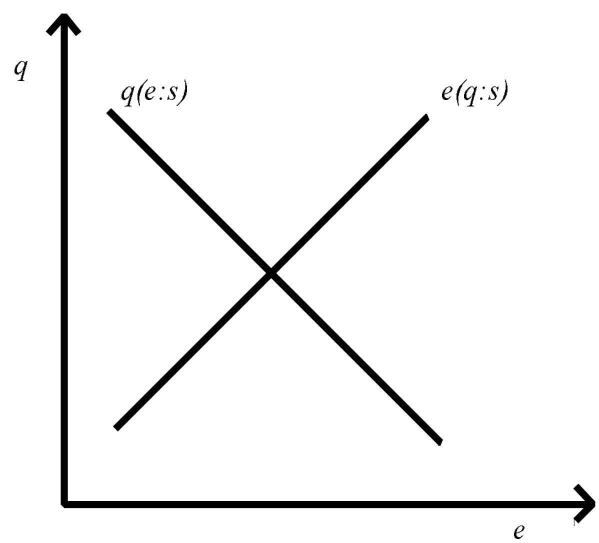
Figure 1a Complements
Case: $P_{es} > 0$



<u>Figure 1b</u> Substitutes

Case: $P_{es} < 0$



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