Received: 6 June 2016 | Accepted: 4 October 2016
DOI: 10.1111/jpet.12238

WILEY JOURNAL OF PUBLIC ECONOMIC THEORY

ARTICLE

Preemptive bribery and incomplete information: Does prior knowledge matter?

Ajit Mishra[1] | **Andrew Samuel**[2]

[1]University of Bath
[2]Loyola University Maryland
Ajit Mishra, Department of Economics, University of Bath, Claverton Down, UK (a.mishra@bath.ac.uk).
Andrew Samuel, Department of Economics, Loyola University Maryland, 4501 N. Charles Street, Baltimore, MD 21210 (asamuel@loyola.edu).

We would like to thank Dilip Mookherjee, Emmanuel Dechenaux, Paul Pecorino, and seminar participants at the Southern Economic Association meetings (2014) for insightful conversations on this topic.

This paper studies bribery between a firm and a supervisor who monitors the firm for regulatory compliance. Bribery occurs preemptively, that is before the supervisor exerts costly effort to discover the firm's level of noncompliance and collect evidence for successful prosecution. In contrast to previous papers, preemptive bribery is modeled as a Bayesian signaling game because the supervisor is uninformed about the firm's level of noncompliance. We show that under normal informational assumptions, some (possibly all) firms always engage in preemptive bribery. However, if knowledge of the firm's level of noncompliance has implications for the supervisor's ability to collect evidence and prosecute (prior knowledge), preemptive bribery can be completely eliminated. Results which apply to preemptive bribery under complete information do not apply here.

1 | INTRODUCTION

It is well recognized that corruption and bribery undermine enforcement in various regulatory settings. In particular, collusion between the supervisor who is in charge of enforcement, and the agent who is being regulated, dilutes enforcement. However, bribery is often undertaken in highly uncertain environments with incomplete information. These informational considerations can put natural limits on the nature and scope of bribery, for example, because the briber does not know which official to bribe or how much to offer. Empirically using cross-country data, Lambsdorff (2007) finds that uncertainty regarding the size of the bribe can reduce corruption. However, a theoretical explanation for why incomplete information places limits on bribery has not been precisely established. This is largely because most of the literature assumes that bribery occurs under complete information. Thus, the objective of this paper is to examine the impact of these informational considerations on the likelihood of bribery. Furthermore, we wish to examine whether the regulator can safely ignore certain types of bribery because asymmetric information makes these unlikely to occur.

To achieve our objective, we consider a model of preemptive bribery where bribery can occur before the supervisor has carried out inspections and the supervisor is relatively uninformed about the firm (agent). Although there is a sizeable literature on corruption and enforcement, most of the focus is on *ex post* bribery; that is, collusion which takes place after the supervisor has collected evidence regarding the firm's noncompliance.[1] Mookherjee and Png (1995), for example, provide a detailed analysis of the conditions under which *ex post* bribery will occur and how it must be deterred (see also Polinsky & Shavell, 2001). Distinguishing between *ex post* and preemptive bribery is important for our project because incomplete information does not have strategic significance for *ex post* bribery—the supervisor is supposed to have conducted the inspection and therefore is in possession of evidence. The supervisor might still be uninformed about certain aspects, but the complete information set-up is not highly restrictive.

In contrast, with preemptive collusion the supervisor accepts a bribe in order to not carry out any inspection (Bac, 1998; Bag, 1997; Motta, 2009; Samuel, 2009). Therefore, it is more likely to be sensitive to informational considerations and assumptions. Indeed, preemptive bribery differs from *ex post* bribery in two crucial aspects, which complicates the analysis of its incentives and deterrence. First, preemptive bribery is more likely to occur because the coalition of the firm and the supervisor saves on the inspection costs by engaging in preemptive bribery. Furthermore, because hard evidence has not been gathered, there is no risk of that evidence "leaking" and being used to prosecute the firm and the supervisor in the future. Second, as we have discussed, preemptive bribery takes place with a relatively uninformed supervisor who does not know the extent of the firm's noncompliance. In this scenario, a firm may be unwilling to bribe the supervisor, because the bribe may signal information about the extent to which the firm is noncompliant. Arguably then, this asymmetric information may be sufficient to disrupt the bargaining process, thereby, preventing preemptive bribery from occurring. *Given that avoiding costly evidence gathering encourages preemptive bribery, while incomplete information discourages it, we wish to examine how these two effects impact the incidence of preemptive bribery in equilibrium*. To our knowledge, ours is the first attempt at fully understanding the implications of asymmetric information for preemptive bribery.

To achieve this goal, we develop a model of bribery in a regulatory setting where polluting firms can be either low-waste or high-waste firms. Different levels of waste attract different mandated fines. The government hires a supervisor who can easily observe whether a firm is nonpolluting or polluting, but cannot distinguish between low- and high-waste firms.[2] To distinguish between low- and high-waste firms, the supervisor must exert costly effort to gather evidence regarding the firm's waste level. Conditional on successfully obtaining evidence, the supervisor is required to report this waste level to the regulator who imposes a fine on the firm based on this report. In the absence of any evidence, a firm is treated as a nonpolluting firm by the legal process. We assume that supervisors are corruptible and may accept a bribe in exchange for not reporting the firm's level of waste to the regulator. If bribery occurs preemptively, the supervisor accepts a bribe in exchange for not gathering evidence regarding the firm's type. The supervisor can commit to not investigate and seek hard information or evidence.

Unlike *ex post* bribery, preemptive bribery occurs before the supervisor observes whether the firm's actual type is known. Therefore, we set up the preemptive bribe game as a signaling game where firms offer bribes to the supervisor and the size of the bribe can potentially signal the firm's type. Using the concept of Bayesian Nash equilibrium, we determine whether preemptive bribery can occur in equilibrium. As is well known, signaling games admit a plethora of equilibria; therefore, we characterize the entire set of (Bayesian Nash) equilibria of this game. Although we identify several equilibria, we show that there exists a unique (separating) equilibrium which satisfies standard refinement criteria. *In this equilibrium, high-waste and low-waste firms offer different bribes which are accepted with different probabilities. As a result, high-waste types always engage in preemptive bribery and escape prosecution, and low-waste types are sometimes prosecuted*. Thus, our first result is that informational asymmetry has limited deterrence and the presence of asymmetric information alone is not sufficient to prevent preemptive collusion completely.

Nevertheless, the standard signaling framework does not fully capture the informational complexities of preemptive bribery. Specifically, in many cases the preemptive bribing process can reveal some information about the firm's level of waste, and this information can make the supervisor's investigation more effective at a later stage in the game.

[1] Empirically preemptive bribery is quite common. See Barron and Olken (2009) for an example where both *ex post* and *ex ante* bribery take place in the trucking industry.

[2] This information structure is often used to capture the hierarchy of information. The firm has the finest, the supervisor has a coarser, and the regulator has the coarsest information structure. For example, see Celik (2009).

If high- and low-waste firms offer a separating bribe, then, because the bribe signals the firm's type, possession of this "soft" information signal may make it easier for the supervisor to subsequently gather hard evidence. To illustrate this intuition in a related context: a detective who knows he is investigating a "small-time crook" may choose to carry out his investigation differently than if he knows he is going after a large, organized gang. Thus, soft information regarding the criminal's type (small or large) can make subsequent evidence gathering more effective.[3] In such a case, informational asymmetries will affect the incidence of preemptive bribery. In this case also the supervisor can commit to "no investigation" after accepting a bribe, but unlike in the previous case he is unable to commit to not using the soft information gained in the process of bribe negotiations.

Given this intuition, we extend our basic model above to allow for the possibility that "knowledge" of a firm's type makes it easier for the supervisor to collect evidence for prosecuting the firm. This possibility, which we identify as the *prior knowledge condition*, affects the preemptive bribery game significantly. Indeed, under this condition, preemptive bribery can be eliminated completely in the sense that there exists an equilibrium in which neither type successfully engages in preemptive bribery. *Thus our paper shows that whether informational asymmetries reduce the feasibility of preemptive bribery depends largely on whether "soft" information obtained through a signal can be utilized by the supervisor to make the subsequent investigation more effective.*[4]

In addition, our comparative static results with and without the prior knowledge condition also differ from standard models of preemptive bribery (Bac, 1998). Specifically, in the previous literature an increase in the cost of inspection effort, or in the probability of detection raise the likelihood of preemptive bribery. In our model with incomplete information, however, an increase in the cost of effort raises the frequency of preemptive bribery among low-polluting firms, but an increase in the probability of detection reduces the likelihood of preemptive bribery among low types. But these parameters (cost of effort, detection probability) have no effect on the likelihood of bribery among high-polluting firms. With the prior knowledge condition, we find that preemptive bribery can be eliminated entirely, and once it is eliminated small changes in these parameters will have no impact on the likelihood of preemptive bribery. Our model, therefore, suggests that the informational structure of the bribe game cannot be ignored when trying to understand the impact of these policy parameters.

The prior knowledge framework that we propose and the results that follow from it illuminate the value of carefully accounting for the informational context in which bribery operates. These results are, therefore, related to the existing literature as to whether a principal can deter collusion (in other contexts) by introducing asymmetric information. Kofman and Lawarrée (1996) study a principal who hires two supervisors to inspect the same firm sequentially. They show that if each supervisor does not know for certain whether she is the first or the second to inspect the firm, collusion can be deterred.[5] Motta (2009) studies preemptive bribery under asymmetric information in a model of tax evasion. In his model, the supervisor only knows the distribution of incomes, but not the income of an individual taxpayer. Therefore, in contrast to our paper where the preemptive bribe may differ according to the level of compliance and may signal the level of compliance, in his paper the supervisor chooses a single (screening) preemptive bribe that maximizes the overall gains from preemptive bribery. Thus, in Motta's paper (2009) preemptive bribery does not provide any information regarding the taxpayer's type, and consequently none of the key findings regarding preemptive bribery under perfect information are altered by the presence of asymmetric information. Our work is also related to Ryvkin and Serra (2012), who study bribery within the context of bureaucrats who illegally provide a public good in exchange for a bribe. In their model, bribery takes place under incomplete information because an individual's moral cost of paying or accepting a bribe is unknown.[6] Bribery, in their set-up, is modeled as a double auction, following the model of bargaining under asymmetric information due to Chatterjee and Samuelson (1983). They show that relative to the case with

[3] Likewise, in certain cases a "confession" to a certain crime may not be admissible evidence, but it can be useful to the inspector in gathering hard evidence.

[4] The basic idea is relevant in other contexts. For example, the informational structure of this game is similar to models of settlement and trial where only the plaintiff knows the true level of damages and makes a settlement demand based on the true level of damages (Reinganum & Wilde, 1986). The defendant infers the plaintiff's true damage level, and must decide whether to settle or let the case go to trial.

[5] Note that in their paper asymmetric information is between multiple supervisors, whereas in our model it is between the supervisor and the agent.

[6] Our paper is also related to the literature on crime and asymmetric information. For example, Marjit, Rajeev, and Mukherjee (2000) show that lack of knowledge about a criminal's type can weaken the law enforcer's incentive to exert costly investigative effort.

complete information, corruption is less likely to occur under incomplete information because bribe payers underbid, and bribe takers overbid, relative to the true value they are willing to pay (accept). Finally, more recently, Chassang and Ortner (2014) have shown that the principal can create and use asymmetric information between the supervisor and the agent as a countercorruption measure. The principal can randomize the incentives given to the supervisor, the realized value being unknown to the agent, and make side-contracting between the supervisor and the agent more difficult.

In contrast to all these papers, our focus is on understanding how the bribing process itself reveals some information about the firm's level of noncompliance, and whether this can in turn influence the effectiveness of inspections. That is, in some sense our prior knowledge condition allows for the possession of "soft information" to make it easy to subsequently collect "hard" information.[7] In this sense, our paper is related to Khalil, Lawarrée, and Yun (2010), who study the role of hard and soft information on bribery and extortion. They assume that information is "hard" when the supervisor acts alone, but becomes "soft" for the supervisor—firm coalition because these parties collude to fabricate evidence. In our model, hard information (or evidence) arises as a consequence of successful evidence gathering, and this evidence gathering is easier if the supervisor possesses soft information.

Besides offering a careful analysis of the informational issues concerning preemptive bribery, our model also explains some empirical patterns regarding preemptive bribery. Specifically, recent empirical findings by Babu, Kumar, and Mehra (2012) suggest that smaller clients are prosecuted more often, while larger clients are able to bribe their way out of being prosecuted. In our model, high-polluting firms are always able to separate themselves from low-polluting firms, and are never prosecuted. Similarly, Lubin's (2003) analysis of bribery among drug smugglers in Afghanistan finds that "big-time" smugglers are more likely to pay preemptive bribes while petty smugglers get apprehended more frequently. Models of preemptive bribery with complete information do not fully explain this particular phenomenon associated with preemptive collusion. However, in our framework we find that the only equilibrium in which bribery occurs is one where the smaller criminals are sometimes prosecuted (and sometimes bribe), but large-scale criminals are always able to pay a bribe to avoid being sanctioned. Thus, introducing incomplete information deepens our understanding of this form of corruption.

Following the introduction, the second section describes the benchmark model under complete information. The third section extends this to the incomplete information setting to see whether bribery gets deterred. In Section 4, we introduce the game with the prior knowledge condition and discuss how preemptive bribery is affected. In Section 5, we study the effect of policy variables both with and without the prior knowledge condition. The final section concludes.

2 | COMPLETE INFORMATION: THE BENCHMARK CASE

Consider a model with three risk-neutral players: the principal or regulator, the supervisor, and the firm. Normalizing the (acceptable) pollution standard to be zero, we have compliant firms with no pollution (0) or noncompliant firms belonging to one of the following two types: low-waste firms with a waste level of l, and high-waste firms with a waste level of h, so that $i \in \{l, h\}$.[8] By assumption, $h > l > 0$. Among the polluting firms the proportion of l types is p (with the corresponding proportion of h types being $(1 - p)$) and each firm knows its type. Supervisors are hired by the regulator to investigate firms who are penalized according to their level of waste. In the complete information setup, the supervisor immediately observes the firm's pollution level; therefore, his information set is $I^C = \{\{0\}, \{l\}, \{h\}\}$. For the compliant firms (with pollution level 0), there is no need for further evidence. For the noncompliant firms, although the supervisor observes the firm type, this information is soft and he must obtain evidence to use in his report to the regulator. By exerting costly effort $E > 0$ the supervisor can, with probability $\mu \in (0, 1)$, obtain evidence regarding the firm's waste level $\{l, h\}$, and with probability $(1 - \mu)$ obtains no evidence $\{\phi\}$. This report is denoted by θ,

[7] Hard information refers to information that is (costlessly) verifiable by third parties (see Baliga, 1999; Tirole, 1992, for a discussion of this issue).

[8] The compliant firms have no strategic role in our analysis, but overall compliance level depends on their measure.

where $\theta \in \{l, h\} \cup \{\phi\}$. The report results in the firm being fined F_i, $i = \{l, h\}$, and the supervisor receives a reward $r_i \cdot F_i$. Following the literature (Shavell, 1992), we assume $F_h > F_l > 0$ for the standard "marginal deterrence" reasons, fines reflecting the intensity of the activity. Depending on the distribution of benefits, some firms may be allowed to pollute at lower levels but not at the higher levels because the latter impose higher social costs. Note that, similar to the fines, rewards can be conditioned on the level of pollution too. However, to keep it simple we assume that $r_h = r_l = r \in (0, 1]$.[9] Furthermore, we assume that firms are not fined when the report $\theta = \phi$.[10] Finally, we assume that the following condition always holds so that we may ignore cases where E is so large (or μ so small) that the supervisor receives a negative payoff from exerting effort to collect evidence:

$$\mu r F_l - E \geq 0. \tag{1}$$

Supervisors and firms are corruptible and may choose to exchange a bribe instead of the fine. In any given interaction between the firm and the supervisor, bribery may occur at two stages: preemptively, that is, before the supervisor has discovered the firm's type, or *ex post*, that is, after the supervisor discovers the firm's type. Under *ex post* bribery the supervisor gathers evidence but submits a report $\theta = \phi$ in exchange for a bribe. Thus, conditional on the supervisor exerting E, *ex post* corruption can occur only with probability μ; that is only if the supervisor finds evidence about the firm's pollution. In contrast, with preemptive bribery the supervisor commits not to investigate further (by not exerting effort) in exchange for a bribe. *We assume that the bribe contract is enforceable and that the supervisor can commit to not investigate the firm after it has accepted a bribe.*

Finally, unlike many models of bribery, we only focus on the use of "carrots" and not "sticks" to prevent bribery. That is, we assume that bribery cannot be detected and penalized. We make this assumption because another layer of supervision opens up the possibility of new forms of collusion between the supervisor and those appointed to monitor the supervisor for bribery, creating further problems in the spirit of the phrase "who will watch the watchmen?"

Under the assumption of sequential rationality, we solve for the subgame perfect Nash equilibrium of this game. First consider the *ex post* bribery game. Any *ex post* bribe B must satisfy, $F > B > rF$. Clearly, by raising $r \geq 1$, this condition can be reversed and *ex post* bribery eliminated (as discussed in Mookherjee & Png, 1995). In the present context, since we also assume $r \leq 1$, this implies $r = 1$ which can be interpreted as the case of privatized enforcement (Laffont & Tirole, 1993).[11] Alternatively, it should be noted that there are often costs associated with *ex post* bribery, especially if suppression of (hard) evidence is costly (as in Khalil *et al*., 2010). If suppressing evidence costs c then $r \geq r' = 1 - (c/F)$ is sufficient to eliminate *ex post* bribery and r need not be set equal to 1. Thus a sufficient condition for preventing *ex post* collusion is

$$r \geq r', \text{ where } r' \leq 1. \tag{2}$$

For the remainder of this paper, we shall assume that (2) is always satisfied since we are primarily interested in the incentives for preemptive bribery. It must be noted that we are not looking at the possible trade-offs or implications of these two forms bribery, but are concerned with the impact of informational asymmetries on the incidence of preemptive bribery alone.

We now turn to the game of preemptive bribery with complete information. Let G^C denote the preemptive bribery (and subsequent investigation) game. We assume that G^C follows a simple ultimatum game where the firm always makes an offer, which the supervisor chooses to accept or reject. Although, these assumptions may appear

[9] Clearly, r is also an instrument through which the regulator can influence the game between the firm and the inspector. However, we find that if $r_l < r_h < 1$, then there is no qualitative change in our results. For $r_l > r_h$, it is possible to get a different set of equilibria but the no-collusion outcome cannot be sustained with $r_l < 1$. For example, with $r_l F_l = r_h F_h$, we have a unique pooling equilibrium with preemptive bribery.

[10] Note that extortion is not feasible in our model because of the requirement of hard evidence for any reporting. An l type cannot be reported as an h type without evidence and we assume that evidence cannot be "cooked."

[11] We can have $r > 1$ but it does not seem realistic, and an unbounded r makes the model uninteresting. Without any upper bound, it is always possible to choose a high enough r to deter all kinds of bribery, including preemptive bribery.

constricting, the key qualitative results are unlikely to be affected.[12] Acceptance of the bribe offer implies that the supervisor will not investigate the firm any further, and rejection means that the supervisor exerts costly effort E to investigate and collect evidence (with probability μ). In the absence of any evidence, $\theta = \phi$ and the firm does not pay any fine. If evidence is obtained, then given (2) the firm pays F_i in fines and the supervisor gets rF_i. A polluting firm of type i will, therefore, offer $(\mu rF_i - E)$ that will be accepted by the supervisor. Because preemptive bribery cannot be detected, for any $r \leq 1$ we have $\mu F_i(1-r) + E > 0$; preemptive collusion cannot be deterred regardless of whether *ex post* collusion is deterred or not. Let U_i denote the expected payoffs to a firm of type i, and let V denote the (expected) payoffs to the supervisor, in game G^C. Equilibrium payoffs are denoted by U_i^*, V^*. We summarize the above discussion in the following claim:

Claim. *In the benchmark case with complete information, in equilibrium both types always engage in preemptive bribery and the firm is never prosecuted, and we have,* $U_i^* = -[\mu rF_i - E], i = l, h$.

3 | INCOMPLETE INFORMATION AND PREEMPTIVE COLLUSION

When the supervisor is unable to distinguish between the l and the h types, preemptive collusion involves an uninformed supervisor. In this game with incomplete information, the supervisor only observes whether the firm is a zero waste firm (compliant) or positive waste firm (of type l or h). Thus, the supervisor's information set I^A now has the partition $\{\{0\}, \{l, h\}\}$. By exerting costly effort $E > 0$ the supervisor can, with probability $\mu \in (0, 1)$, obtain evidence regarding the firm's waste level. Note that possession of evidence implies knowledge of the firm's type but the converse is not true.

The preemptive bribe game with incomplete information, which we denote by G^A, is a signaling game. In this game, the polluting firm makes a bribe offer, and where p is the supervisor's prior belief that the firm is of type l. A firm of type i's strategy is denoted by the bribe offer B_i, where $B_i \geq 0$, while the supervisor's strategy is denoted by $a \in \{0, 1\}$, where $a = 1$ denotes acceptance of the bribe.[13] Following a preemptive bribe offer $B \in R_+$, the supervisor updates its belief about the firm's type, where q denotes the supervisor's posterior belief that the firm is of type l, $q(B) = prob(i = l \mid B)$. Besides the bribe, we assume that the supervisor does not receive any other signals. Rejection, $a = 0$, leads to the supervisor putting in the required effort to collect the evidence. Let $\rho(a \mid B) \equiv \rho(B)$, with $\rho : R_+ \longrightarrow [0, 1]$, be the probability that a bribe offer B will be accepted.

We denote the game's strategy profile as $\sigma = (B_l, B_h, \rho(B))$, and shall consider sequential equilibria $(\sigma^*, \widetilde{q})$ where σ^* is sequentially rational given system of beliefs $\widetilde{q}$, and $\widetilde{q}$ is consistent with σ^*, Bayes' law, and the given prior p. First, we examine whether the no-collusion outcome is an equilibrium (that is, whether preemptive bribery can be prevented). Then, we consider two types of preemptive bribe equilibria: (1) pooling equilibria where both types of firms offer the same positive bribe and the supervisor accepts the bribe, and (2) separating equilibria where h types offer a separating bribe B_h^* and the l types offer B_l^*, and the supervisor accepts the higher bribe from the h type while rejecting the lower bribe with positive probability. In the separating equilibrium, there is preemptive collusion with the h type but the l type is being investigated and penalized with positive probability.

As is well known, these games admit many equilibria which are often supported by unreasonable out-of-equilibrium beliefs. We use a version of the universal divinity criterion (Banks & Sobel, 1987; Cho & Sobel, 1990) to refine the set of equilibria. Refinement in this context essentially eliminates types for a certain strategy B if they are unlikely to have deviated to that strategy B (given the other players' best response to B). We use the following condition, denoted as $D1$, to refine the set of equilibria (see Fudenberg & Tirole, 2000).

[12] Our model implies that the firm possesses all the bargaining power. Most bribery games determine the bribe within a Nash bargaining framework with equal bargaining power. However, this bargaining solution cannot be extended easily to incomplete information settings. As an alternative to the above assumption, we have considered another variant of the ultimatum game where the supervisor and the firm each make an offer (or bribe ask) with probability 0.5. Qualitative results are unchanged.

[13] Since we only focus on pure strategy bribe offers by the firm, the equilibria we consider are exhaustive. Allowing firms to randomize over different bribe introduces the possibility of other equilibria, such as semiseparating equilibria. However, our basic results remain unchanged.

Consider any particular equilibrium $(\sigma^*, \widetilde{q})$ and let U_l^*, U_h^* be the equilibrium payoffs of the two types in the game G^A. Type i will benefit from deviating to bribe offer B if $U_i(B,\rho) > U_i^*$. Let P be the set of mixed best responses by the supervisor for any beliefs q over types. Define $D(B,i)$ as the set of mixed best responses by the supervisor so that type i benefits from deviating. That is,

$$D(B,i) = \{\rho \in P \text{ s.t. } U_i(B,\rho(B)) > U_i^*\}, i = l, h. \tag{3}$$

Similarly, define $D^0(B,i)$ as the set of best responses by the supervisor so that type i is indifferent between the equilibrium play and deviation to offer B. Then,

$$D^0(B,i) = \{\rho \in P \text{ s.t. } U_i(B,\rho(B)) = U_i^*\}, i = l, h. \tag{4}$$

Condition 1. Condition D1 requires that a type i is not considered for deviation B if $\exists j \neq i$ s.t.

$$\{D(B,i) \cup D^0(B,i)\} \subset D(B,j) \tag{5}$$

The condition requires that type i is not likely to have deviated to offer B if there exists another type j such that, whenever type i finds it profitable to deviate, so does type j, but the converse is not true. An equilibrium is rejected if out-of-equilibrium beliefs fail to satisfy this condition.

3.1 | Preventing collusion

Recall that in the complete information benchmark case, it is not possible to prevent preemptive collusion by either type of firms, whenever $r \leq 1$. In the incomplete information case, we now show that it is possible to achieve some, but not complete, deterrence. Specifically, it is easy to show that the no-collusion outcome, where neither type engages in preemptive bribery, cannot be sustained as an equilibrium. We outline the logic of this claim below by showing, in the following paragraphs, that strategies in which both types offer a 0 bribe or where the supervisor always rejects any bribe (from either type) do not constitute an equilibrium.

Let B_l^*, B_h^* refer to the equilibrium bribe offers by the two types. For the no-collusion outcome to be an equilibrium, it must be the case that $\rho^*(B_l^*) = \rho^*(B_h^*) = 0$, or that $B_l^* = B_h^* = 0$. First, observe that it is not rational for the supervisor to reject any bribe offer $B \geq \mu r F_h - E$. Hence any equilibrium bribe from either type must satisfy $B_l^*, B_h^* < \mu r F_h - E$. Limiting our bribes to this range, there may be pooling equilibria with $B_l^* = B_h^*$ or, a separating equilibria with $B_l^* < B_h^*$. However, regardless of whether it is pooling or separating, if the no-collusion outcome is an equilibrium the payoff to the h type is μF_h. But then the h type can always deviate and offer $\mu r F_h - E$ which will be accepted.[14] Since $r \leq 1$, it follows that $\mu r F_h - E < \mu F_h$, and such a deviation is always profitable. Thus, no-collusion cannot be an equilibrium. We summarize this analysis in the following proposition.

Proposition 1. *In the incomplete information environment, complete prevention of preemptive bribery is not possible.*

This establishes that the presence of asymmetric information in itself is not sufficient to deter preemptive bribery. However, we shall see that compared to the benchmark case in Section 2, there is some deterrence of preemptive bribery. We shall show that the h types will always engage in some form of preemptive bribery in any equilibrium. The extent to which the l types engage in bribery depends on the particular equilibrium we focus on.

3.2 | Preemptive bribery and limited prosecution

Clearly, game G^A admits several equilibria, therefore, the nature of preemptive bribery and whether prosecution will occur depends on the specific equilibrium. As mentioned earlier, in this game both pooling as well as separating

[14] Note that this is true even if $r_h > r_l$ because the high type will always be able to offer a separating bribe and deviate.

equilibria exist.[15] In the case of pooling, both types of firms are able to enter into preemptive collusion with the supervisor with positive bribes $B_l = B_h = B^* > 0$, which the supervisor accepts. It should be noted that there is in fact a multiplicity of such pooling equilibria. Any bribe B^* such that $\underline{B} \le B^* < \min\{\mu F_l, \mu r F_h - E)\}$ can be supported as an equilibrium, where $\underline{B}$ stands for the bribe which the supervisor is indifferent between accepting and rejecting, for a given prior belief p.

With regard to separating equilibria, as one would expect, the h types are able to offer large enough bribes to separate from the l types. Specifically, each type offers different bribes which are accepted with different probabilities. The most obvious separating equilibrium is one where the l types offer zero bribe, which is rejected by the supervisor. This equilibrium with preemptive bribery by only the h type is possible only when the marginal fine $(F_h - F_l)$ is quite large: $\mu r F_h - E \ge \mu F_l$. However, as we show in the appendix, it requires beliefs that do not satisfy the condition $D1$ specified earlier.

Although the above equilibrium does not satisfy refinements, there is a second separating equilibrium which does. In this equilibrium, the h types offer B_h^* which is accepted with probability 1 and the l types offer B_l^* which is accepted with probability $x < 1$ such that the h types are not interested in mimicking the l types. Also, this equilibrium does not depend on whether $\mu r F_h - E \ge \mu F_l$ holds or not. We characterize the equilibrium below and show that it is unique in the sense that it satisfies the divinity criterion stated earlier.

Consider the following equilibrium: $B_l^* = \mu r F_l - E$ and $B_h^* = \mu r F_h - E$. The supervisor's strategy is given by

$$\rho^*(B) = \begin{cases} 1, \text{ for } B \ge B_h^* \\ x, \text{ for } B = B_l^* \text{ where } x = \frac{\mu F_h + E - \mu r F_h}{\mu F_h + E - \mu r F_l}, 0 < x < 1 \\ 0, \text{ otherwise.} \end{cases} \tag{6}$$

The corresponding belief system $\tilde{q}$ is given as follows:

$$\tilde{q}(B) = \begin{cases} 0, B > \mu r F_l - E \\ 1, \text{ otherwise.} \end{cases} \tag{7}$$

Proposition 2. *Let $r \ge r'$, so that ex post collusion is not feasible. In this incomplete information environment, there always exists an equilibrium where the h type engages in preemptive bribery and is never prosecuted and the l type engages in bribery but is prosecuted with positive probability* $1 - x; x = (\frac{\mu F_h + E - \mu r F_h}{\mu F_h + E - \mu r F_l}) \in (0, 1)$. *This equilibrium satisfies condition* $D1$.

Proof. *First, note that for an x to exist such that the h type is indifferent between mimicking the l type and separating (offering B_l^* and B_h^*) we need an x such that*

$$\mu r F_h - E = x(\mu r F_l - E) + (1 - x)(\mu F_h).$$

Clearly, such an x always exists since $\mu F_h > \mu r F_h - E > \mu r F_l - E$.

With this x, it is easy to verify that the strategy profile and beliefs specified above constitute an equilibrium.[16] *The h type is indifferent between offering B_h^* and B_l^*, hence it has no incentive to deviate. The l type does not benefit from deviation either. Any bribe below $\mu r F_l - E$ will be rejected and will lead to a payoff of $-(\mu F_l) < -[x(\mu r F_l - E) + (1 - x)\mu F_l]$. Note that any offer below $\mu r F_l - E$ will be rejected irrespective of the belief about the types. It can be verified that the l type will also be strictly worse off by offering any bribe $B \ge B_h^*$. For the supervisor, rejecting any bribe offer between $\mu r F_l - E$ and $\mu r F_h - E$ is optimal because the supervisor believes that such offer would have come only from the h type. We can verify that beliefs satisfy condition $D1$. Recall that equilibrium payoffs are*

$$U_h^* = -[\mu r F_h - E], U_l^* = -[x(\mu r F_l - E) + (1 - x)\mu F_l]. \tag{8}$$

[15] We characterize the entire set of equilibria in the appendix. However, we do not consider mixed strategies where firms randomize over bribes.

[16] To show that such a construction exists, it suffices to note that $0 < x < 1$. Suppose $p = 1/2, F_h = 40, F_l = 20, E = 2, \mu = 3/5, r = 3/4$. The h type offers 16 which is accepted, the l type offers 7 which is accepted with probability $8/17$. So the l type is prosecuted with probability $9/17$.

Now consider a deviation to bribe B by the firm such that $\min\{\mu F_l, \mu r F_h - E\} > B > \mu r F_l - E$. Note that we do not need to consider deviations below $\mu r F_l - E$ because such bribes will always be refused; it is the least the supervisor gets from refusing. Similarly, bribes which exceed μF_l can only originate from the h types and bribes in excess of $\mu r F_h - E$ are accepted in equilibrium. For any such deviation B, we can find the set of mixed best responses by the supervisor for which such a deviation would yield higher payoffs compared to the equilibrium payoffs for the two different types. Using (3) and (4),

$$\begin{aligned} D(B,h) &= \left\{ \rho \in P \mid \rho > \rho_h = \frac{\mu F_h + E - \mu r F_h}{\mu F_h - B} \right\}, \\ D(B,l) &= \left\{ \rho \in P \mid \rho > \rho_l = \frac{x(\mu F_l + E - \mu r F_l}{\mu F_l - B} \right\}, \\ \text{and } D^0(B,l) &= \rho_l \\ \text{where } x &= \frac{\mu F_h + E - \mu r F_h}{\mu F_h + E - \mu r F_l}. \end{aligned} \tag{9}$$

Given that $(\rho_h - \rho_l) = \frac{x}{(\mu F_h - B)(\mu F_l - B)}(\mu r F_l - E - B)(\mu F_h - \mu F_l)$, it is easy to see that $\rho_h < \rho_l$, $\forall B > \mu r F_l - E$. It follows that $\{D(B,l) \cup D^0(B,l)\} \subset D(B,h)$. Hence, according to D1, given any bribe offer in excess of $\mu r F_l - E$ the supervisor should believe that the offer would have been made by the h type rather than the l type. This is what the beliefs as given in (7) specify. ■

In the appendix, we show that no other equilibrium satisfies condition *D*1 and we can treat the above (6) as the unique equilibrium. Specifically, it shows that the *l* types do get prosecuted with some probability while the *h* types are never prosecuted. Thus, incomplete information, in this sense, does reduce preemptive bribery and raises prosecution. In Section 5, we study the comparative static effects of the policy variables and show that lack of information does affect many previous results concerning preemptive bribery.

4 | PRIOR KNOWLEDGE AND PREEMPTIVE BRIBERY

In the previous section, we have implicitly assumed that the probability, μ, of gathering hard information or evidence is independent of whether the supervisor is knowledgeable about the firm's type or not. This assumption is present in different forms in much of the literature. In many models (e.g., Mookherjee & Png, 1995), all information is hard information and hence there is no difference between detection of types and evidence gathering. In models where a distinction between hard and soft information is made (e.g., Samuel, 2009), the supervisor always knows the types but to gather hard information (or what we have also referred to as evidence) the supervisor needs to incur positive cost. In contrast, here the supervisor does not know the types initially but can learn about the types without (and before) collecting evidence.[17] The key question here is: does prior knowledge of the types make it easier to collect evidence? We believe that in many settings it does. For example, a suspect in a criminal trial may admit to the crime. Although this admission of guilt is inadmissible in court, nevertheless this knowledge can make it easier for a detective to find evidence against the suspect. Similarly, it is common for an investigative journalist to know of a particular political scandal (perhaps because the knowledge is obtained through "unnamed sources"), and this knowledge can make it easier for the journalist to obtain evidence regarding this scandal.

In this present context, any separating bribe offer must reveal something about the firm's type because each type of firm offers a different bribe. Although this information may not be hard, this knowledge of firms' types will make it easier for the supervisor to obtain evidence regarding the firm's type.[18] We formalize the concept that knowledge translates into more effective evidence gathering through the following *Prior Knowledge Condition*.

[17] It is quite common for agents, in various economic settings, to learn or know through communication, signaling, and different methods of inference.

[18] Alternatively, one could assume that the belief that an individual is a high polluter (with probability 1) encourages the supervisor to exert more effort, because she knows she will find evidence. This is not technically feasible in our model because effort is discrete. However, if effort were continuous, this alternative assumption would yield similar results.

Prior Knowledge Condition: *Suppose the supervisor believes the firm to be of a certain type with probability 1: the probability ($\mu^{/}$) of obtaining hard information against this particular type, upon exerting effort E, is always higher than the probability (μ) of obtaining hard information against a type of firm that the supervisor is not sure about.*

It is important to note that this condition is not meant to be a refinement criterion (like $D1$); rather, it modifies the actual game being played by the supervisor and the agent. Hence, we denote the game with prior knowledge by G^K. In addition, in this game the supervisor does not commit to not using the information gained during the bribe negotiation. However, once it receives a bribe from the firm, the supervisor commits not to investigate, as in the previous section.

In this game, the expected payoffs to the supervisor and the agent following a rejection of a bribe offer are affected by this condition. When the supervisor is faced with a bribe offer which tells him that it has to be from a certain type, its expected payoff goes up because he is able to gather evidence with a higher probability. Note that this applies uniformly across the types, irrespective of whether it is l or h. In this section, we require that the equilibrium outcome should satisfy the prior knowledge condition. In other words, we require that $\mu' = \mu(1) > \mu(q)$ for $q < 1$. While our results hold for any μ' such that $\mu' r > \mu$, for simplicity we assume that $\mu' = 1$.[19] Note that previously the h types were always able to separate from the other type and engage in preemptive bribery. But now there is a trade-off, because once revealed the expected rewards to the supervisor will be higher and the minimum bribe required to engage in preemptive bribery will be correspondingly higher. Thus, the prior knowledge condition introduces a cost to the h type for choosing a (separating) bribe that reveals its type. This cost creates a disincentive for preemptive collusion. The following proposition confirms this intuition.

Proposition 3. *Suppose $r \geq r'$. In the prior knowledge game, the no-collusion outcome can be implemented as the unique equilibrium if the fine for the h type can be raised sufficiently.*

Proof. *Note that we continue to assume $r \geq r'$ so that* ex post *collusion is always prevented. First, we show that the no-collusion (NC) outcome can be an equilibrium. Consider the equilibrium strategy profile,*

$$\sigma^*_{NC} : B^*_l = 0, B^*_h = 0, \rho^*(B) = 0, \forall B \leq rF_h - E. \tag{10}$$

The corresponding belief system is given by

$$\widetilde{q}_{NC}(B) = \begin{cases} p, \ B = 0 \\ 0, B > 0. \end{cases} \tag{11}$$

It is easy to verify that $(\sigma^*_{NC}, \widetilde{q}_{NC})$ is an equilibrium if $\mu F_h \leq rF_h - E$. By not entering in to a preemptive bribery deal, the firm faces full penalty F_h, but with a reduced probability $\mu < 1$. With preemptive bribery, given KC, *it has to pay a higher bribe $rF_h - E$. In the absence of* PKC, *the minimal separating offer by the h type is $\mu rF_h - E$, whereas with* PKC *this goes up to $rF_h - E$. Hence, to guarantee the existence of this equilibrium we need*

$$r \geq \mu + \frac{E}{F_h}, \text{or } F_h \geq \frac{E}{r - \mu}. \tag{12}$$

To see that preemptive bribery cannot be sustained, consider the separating and pooling equilibria discussed earlier. The h type will prefer to be inspected if (12) *is satisfied, $rF_h - E > \mu F_h$, which reduces to $(r - \mu)F_h > E$.*[20] *Thus we cannot have any separating equilibrium of the type discussed in Section 3.2.*

Now consider the pooling equilibria with positive bribes. In any pooling equilibrium bribery does not reveal any information about the firm's type, hence $q = p$. Therefore, for the supervisor to accept the pooling bribe B^* with positive probability, it must satisfy

$$B^* \geq \mu r[pF_l + (1 - p)F_h] - E.$$

[19] Furthermore , note that if $\mu' r < \mu$, then the equilibrium results of Proposition 2 would apply.

[20] The corresponding case when $\mu' < 1$ will be $F_h \geq \frac{E}{\mu' r - \mu}$.

This bribe must also be individually rational for the low types, therefore,

$$B^* < \mu F_l.$$

Combining the two previous inequalities, it follows that a pooling equilibrium with preemptive bribery can exist only if

$$\mu[(rF_h - F_l - rp(F_h - F_l)] < E. \tag{13}$$

Hence, pooling equilibria (described in the appendix, Equation A3*) can be eliminated if the above inequality* (13) *is reversed, that is,*

$$F_h \geq F_h^{/}, \text{ where } F_h^{/} \text{ is given by } \mu[(rF_h^{/} - F_l - rp(F_h^{/} - F_l)] = \mu F_l. \tag{14}$$

Hence, the no-collusion equilibrium is unique for $F_h \geq \max\{F_h^{/}, \frac{E}{r-\mu}\}$*.* ■

This shows that a combination of high rewards for the supervisor and high fines for the h type firms can deter both forms of collusion. Our analysis relied heavily on the regulator's ability to set F_h at a sufficiently high level. This may not be feasible for various reasons, for example, fines might be subject to some limited liability constraints.

5 | POLICY ANALYSIS

In this section, we study the comparative static effects of policy parameters r, F_i, E, and μ. We show that incomplete information (both with and without the prior knowledge condition) affect previous comparative static results in the literature regarding preemptive bribery. We assume that any of these comparative static changes always satisfy the restrictions imposed on these parameters in Section 2.

Proposition 4. *The comparative static effects of the policy parameters in the three games: full information, incomplete information without the prior knowledge condition, and incomplete information with the prior knowledge condition are as follows:*

- *Full information game (G^C): A small increase in r, F_i, E, and μ has no impact on the incidence of bribery or the likelihood of prosecution of either type of firm. However, an increase in r, F_i, μ increases the size of the preemptive bribe, while an increase in E decreases the size of the preemptive bribe. However, none of these parameters can be chosen in a way to eliminate preemptive bribery.*
- *Incomplete information, no prior knowledge (G^A): In the unique equilibrium that satisfies D1, the following comparative statics hold. A small increase in r, F_h and μ increases the likelihood of prosecution of the l types, and a small increase in E or F_l decreases the likelihood of prosecution of the l types. The likelihood of prosecuting the h types is unaffected by any of these parameters. However, for any of these policy parameters, preemptive bribery will always occur for the h types and sometimes for the l types.*
- *Incomplete information, with prior knowledge (G^K): A small increase in μ increases the likelihood of prosecution of both types. But none of the other parameters have any effects on the equilibrium likelihood of prosecution. Furthermore, there exist policy parameters for which preemptive can be eliminated entirely.*

Proof. *First, consider the game with full information. As we have seen in the Claim in Section 2, bribery can never be eliminated. The rest of the comparative static results follow from observing that $U_i^* = -[\mu rF_i - E]$.*

Second, consider the game with incomplete information, but without the prior knowledge condition (Section 3). First note that, without the knowledge condition, preemptive bribery cannot be prevented even with higher μ and lower E, since $\mu F_h > \mu rF_h - E$ even when E is close to 0 (because $r < 1$). Second, from the expression for x in Proposition 2, we can verify that $\frac{\partial x}{\partial r} < 0$, $\frac{\partial x}{\partial \mu} < 0$, $\frac{\partial x}{\partial F_l} > 0$, $\frac{\partial x}{\partial E} > 0$, and $\frac{\partial x}{\partial F_h} < 0$. Since the probability of prosecution is simply $(1 - x)$, the claim in the proposition easily follows. Finally, as Proposition 2 shows, preemptive bribery always occurs for the h types and sometimes for the l types.

Third, consider the game with the prior knowledge condition (Proposition 3). We know that preemptive bribery can be eliminated entirely. The comparative static results follow directly from this. That is, μ is the only parameter that can affect the likelihood of prosecution. However, note that the prior knowledge condition makes a significant impact only when μ is not too large. As μ is raised preemptive bribery becomes more attractive and it may not be possible to guarantee the no-collusion outcome. ■

Proposition 4 identifies the key impact of information with regard to the ability to fight corruption using carrots versus sticks. As discussed previously, being able to use only carrots to eliminate bribery is important because penalties for bribery simply create more opportunities for bribery, whereas this problem does not arise if the regulator can eliminate bribery only through carrots. Prior results in the literature show that *ex post* bribery can always be eliminated through rewards r but preemptive bribery cannot be eliminated through carrots alone. Under complete information, this still holds true. Under incomplete information without the prior knowledge condition, preemptive bribery can only be partially eliminated through the use of carrots alone. However, in the game with the prior knowledge condition, preemptive bribery can be completely eliminated through the use of only carrots (as long as r satisfies Equation 12). Thus, what matters for the elimination of bribery only through carrots is not simply the lack of information, but rather whether that information translates into better investigative abilities for the supervisor. Or, interpreted alternatively, whether or not the supervisor can commit to not use the information she learns about the firm (from the bribe offer) in any subsequent investigations, should that bribe negotiation break down.

The above comparative static results are also interesting relative to those discussed in Bac (1998) and Samuel (2009). Specifically, in these papers when preemptive bribery occurs under full information, an increase in the supervisor's ability to monitor (μ), an increase in cost of evidence gathering E, and an increase in the penalty F always increase the likelihood of preemptive bribery. In contrast, with incomplete information an increase in μ reduces the likelihood of preemptive bribery among low types (by lowering x), while not affecting the incentives for bribery among the high types. However, an increase in E raises x thereby increasing the frequency of preemptive bribery among the low types. Furthermore, the fines have opposing effects in that an increase in F_l increases the incidence of bribery among l types, whereas an increase in F_h decreases preemptive bribery among l types, but neither of these fines impact the likelihood of bribery among h types.[21] As F_l is raised, B_l also goes up leading to increased chances of the bribe offer being accepted by the supervisor, while keeping the incentive compatibility condition for the h type satisfied.

The comparative static effects of μ and E are particularly important from a policy standpoint because they offer insight as to whether improvements in technology can reduce the incentives for bribery. Bac (1998) and Bag (1997) show that an improvement in the supervisor's ability to monitor the firm can manifest itself in the form of lower effort costs E (for a given level of monitoring μ), or an increase in supervisor's ability to monitor the firm μ for a given level of effort. They show that these two effects are asymmetric. That is, a decrease in the cost of monitoring E always discourages preemptive bribery, while an increase in μ encourages it. In contrast, here in the game without the prior knowledge condition, an improvement in the supervisors monitoring technology (either through a reduced E or higher μ) always reduces the frequency of preemptive bribery among l types. Thus, in contrast to these previous papers who argue that improvements in the monitoring technology may not be desirable since they encourage bribery, here we show that *in the presence of asymmetric information, improvements in monitoring technology are always desirable.* Thus, the results regarding the incentives for preemptive bribery (even in the absence of the prior knowledge condition) stand in sharp contrast to those in the existing literature.

A final policy issue remains. Thus far, we have looked at the interactions between the firms and the supervisor, taking the enforcement regime to be given. Furthermore, the fraction of l and h types was exogenous. However, the regulator can potentially choose fines, rewards, and investigation intensity optimally. These fines will in turn affect the fraction of firms that belong to each type. While a formal treatment of this regulatory problem is beyond the scope and focus of this paper, we now sketch an extension to discuss the implications of our paper for compliance and optimal policy.

We consider an extension of our model in the spirit of Shavell (1992). There are a finite number of equally likely types $t = 1, 2 \ldots .T$. Each type can choose whether to pollute 0, l, or h, where type t receives a benefit of tg_i for $i = \{0, l, h\}, g_h >$

[21] This also opens up the possibility that the regulator might impose different fines for firms even when they generate the same social harm, in order to create artificially distinct types.

g_l.[22] This framework essentially follows Shavell's "two-act model" of marginal deterrence; therefore, the result follows that a socially optimal planner will set $F_h > F_l$.[23]

Turning to endogenous compliance and bribery. Pollution decisions will depend on the gains from polluting (level i) and the expected cost associated with it (U_i^*). For example, a firm of type t will choose no pollution to l if $tg_l - \mu F_l \geq 0$. Thus, all firms with $t \leq \frac{\mu F_l}{g_l} \equiv t_l$ will choose not to pollute. Similarly, a firm of type t will choose l over h if $tg_l - \mu F_l \geq tg_h - \mu F_h$. That is, all firms with $t \geq \frac{\mu(F_h - F_l)}{g_h - g_l} \equiv t_h$ choose h. Thus, all types $t \leq t_l$ will choose not to pollute, $t_l < t \leq t_h$ will pollute l and $t > t_h$ will pollute h. In the absence of corruption, the fraction of firms choosing zero pollution is $\frac{\mu F_l}{Tg_l}$, the fraction of firms choosing high level of pollution h is $1 - \frac{\mu F_h}{Tg_h}$ with the remaining fraction choosing low pollution. In this equilibrium, because bribery affects the expected cost associated with any pollution level, the fraction of firms for each level of pollution will be affected by bribery. Specifically, with preemptive collusion; payoffs are $tg_l - [\mu r F_l - E] > tg_l - \mu F_l, tg_h - [\mu r F_h - E] > tg_h - \mu F_h$. Clearly, t_l, t_h will be lower with preemptive collusion; therefore, there is less compliance. With incomplete information, expected payoff from high pollution stays the same, but the payoff from low pollution is lower because low pollution firms get prosecuted with some probability and their expected payoff is $tg_l - [x(\mu r F_l - E) + (1 - x)\mu F_l] > tg_l - \mu F_l$, where $x < 1$ and $\mu r F_l - E < \mu F_l$. Compared to the full information preemptive bribery case, now there are more firms choosing zero pollution (and not bribing) and t_l is higher. Thus, incomplete information does reduce bribery.[24] Under prior knowledge the impact of incomplete information is further strengthened because bribery is eliminated completely. Therefore, compliance returns to the original (no corruption) levels of t_h and t_l.[25]

6 | CONCLUSION

The goal of this paper is to understand the possible limits that incomplete information places on the incentives and scope for preemptive bribery. We show that the incentives for preemptive bribery are strongly influenced by the presence of asymmetric information. However, the degree of influence depends on whether the prior knowledge of a firm's type makes it easier to collect evidence. To reflect this possibility, we introduce the prior knowledge condition, which states that the supervisor's probability of gathering hard information regarding the firm's waste level is higher when the supervisor has prior knowledge of the firm's waste level (type). This condition introduces a cost to the informed party for choosing a separating strategy in a signaling game, which as we show is critical.

In the absence of the prior knowledge condition, asymmetric information prevents preemptive bribery, but only to a limited extent. Specifically, with incomplete information h type firms always engage in preemptive bribery while l type firms do so with some probability and are prosecuted the rest of the time (Proposition 2). Thus, an outcome in which neither type (ever) engage in bribery cannot be sustained as an equilibrium. However, relative to the case with full information (in which bribery always occurs), incomplete information does limit bribery, at least among low-polluting firms.

With the prior knowledge condition, knowledge obtained through the bribing process makes evidence gathering more effective. Consequently, the h types' incentive to separate and engage in preemptive bribery now comes at a cost, and the minimum bribe required to separate is significantly higher under the prior knowledge condition. Thus, in contrast to the case without the prior knowledge condition, informational constraints completely eliminate preemptive bribery under certain reasonable conditions.[26]

Although we have focused on the implications of the prior knowledge condition for bribery, this condition can be applied to a variety of situations. For example, it may apply to settlement and litigation within the context of tort

[22] This choice structure essentially makes the types in our model (Section 2) the "derived" types.

[23] For example, if $T = 2$, it can be shown that $F_l = \frac{g_l F^{\max}}{2g_h - g_l}$, $F_h = F^{\max}$, where the maximal fine $F^{\max}$ depends on the legal limits on fine or wealth constraints of firms. It can be checked that the relevant incentive constraints $2g_h - \mu F_h \leq 2g_l - \mu F_l \leq 0$, and $g_l - \mu F_l \leq 0$, $g_h - \mu F_h \leq 0$ are satisfied and μ is minimized.

[24] For the example in footnote 16, the low types expected payments change from 7 to 13.8. The high types continue to pay 16.

[25] Note that in a pooling equilibrium the prior knowledge condition does not apply. Hence the results of Proposition 3 with regard to pooling can be applied.

[26] However, it should be noted that whether the prior knowledge condition is valid will depend on the specific context in which preemptive bribery occurs.

suits, where the defendant but not the plaintiff knows the true extent of the damages. Our model suggests that when the prior knowledge condition applies, then pretrial settlements are less likely to occur, in contrast to what standard models predict (Reinganum & Wilde, 1986).[27] Relatedly, the preemptive bribe negotiation is similar to the negotiation between a defendant and a prosecutor (or district attorney) because this negotiation also occurs before the prosecutor has gathered all the evidence. Our model with the prior knowledge condition may also explain the behavior of defendants within the context of plea bargaining offers. However, we leave the application of our condition in these areas for future work.

APPENDIX

In the following paragraphs, we examine the various equilibria discussed in the text to see whether the out-of-equilibrium beliefs specified by these equilibria are deemed reasonable. As mentioned in the text, we adopt the universal divinity criterion as characterized in Fudenberg and Tirole (2000) and refer to it as condition $D1$. Before proceeding to apply this criterion to the equilibria described in Section 3, the set of equilibria can be characterized as follows. We have three types of equilibria, as we explain below. It must be pointed out that we are restricting attention to pure strategy bribe offers only; it is possible to have other equilibria with mixed offers.

(1) *If* $(\mu rF_h - E) - \mu F_l > \mu rp(F_h - F_l) > 0$, then we have two types of equilibria. (A) First, there is a separating equilibrium (discussed in Section 3.2) where $B_l^* = 0$ and $B_h^* = (\mu rF_h - E)$ and $\rho^*(B) = 1 \forall B \geq B_h^*, 0$ otherwise. (B) Second, we (always) have the separating equilibrium of Proposition 2; $B_l^* = \mu rF_l - E$ and $B_h^* = (\mu rF_h - E)$ and $\rho^*(B) = 1 \forall B \geq B_h^*, \& \rho^*(B) = x < 1, B = B_l^*, 0$ otherwise.

(2) If $\mu rp(F_h - F_l) > (\mu rF_h - E) - \mu F_l > 0$, we have three types of equilibria, (A), (B), and (C). In addition to the above two we also have a (C) pooling equilibrium $B_i^* = B^*, i = l, h, B^* \geq \mu r[pF_l + (1-p)F_h] - E, \rho^*(B) = 1 \forall B \geq B_h^*, 0$ otherwise.

(3) If $\mu rF_h - E \leq \mu F_l$, then we have only two types of equilibria, (B) and (C).

In the text we have shown that separating equilibrium (B) satisfies $D1$ (Proposition 2). Here we show that equilibria (A) and (C) do not satisfy $D1$.

Separating equilibrium (A):

Suppose $\mu rF_h - E > \mu F_l$. Define $B_l^* = 0$ and $B_h^* = (\mu rF_h - E)$. It can be shown that there exists a strategy profile σ^* and system of belief $\tilde{q}$ such that $(\sigma^*, \tilde{q})$ is a sequential equilibrium. The strategy profile σ^* is given by

$$B_l^* = 0, \; B_h^* = \mu rF_h - E \tag{A1}$$

$$\rho^*(B) = \begin{cases} 1, \forall B \geq B_h^* \\ 0, \text{ otherwise.} \end{cases}$$

The corresponding belief system $\tilde{q}$ is given as follows:

$$\tilde{q}(B) = \begin{cases} 1, B = 0 \\ 0, \text{otherwise.} \end{cases} \tag{A2}$$

The supervisor believes that any positive bribe offer must be from the h type. Given this belief, the supervisor will not accept any bribe which is less than $\mu rF_h - E$. This is the payoff the supervisor gets from rejecting a bribe offer when faced with the h type firm. The l types pay no bribe and face investigation and do not benefit from deviating given the beliefs and strategy of the supervisor. Equilibrium payoffs of the two types are $U_h^* = -[\mu rF_h - E], U_l^* = -[\mu F_l]$. Consider a deviation to bribe $B > rF_l - E$. Recall that any offer below this will always be rejected. Type h would deviate to B if $\rho B + (1-\rho)\mu F_h < \mu rF_h - E$ where ρ is the probability that B will be accepted. Hence, $D(B, h) = \{\rho \in P \mid \rho > \rho_h = \frac{\mu F_h + E - \mu rF_h}{\mu F_h - B} <$

[27] A key difference, however, is that in our model the inspector can commit to not investigate; this commitment may not always be possible in some legal contexts.

$1\}$. For the l type, deviation to B is profitable if and only if $\rho B + (1-\rho)\mu F_l < \mu F_l$. Hence $D(B,l) = \{\rho \in P \mid \rho > 0\}$. Clearly, $D(B,h) \subset D(B,l)$; therefore, the l type is more likely to have deviated to B. The out-of-equilibrium belief $q(l \mid B > 0) = 0$ is not consistent with $D1$.[28]

Note that we do not have separating equilibria of this type when $\mu r F_h - E \leq \mu F_l$. The only separating equilibrium in such a case is the one discussed Proposition 2.

Pooling equilibrium (C):

Suppose $\mu r p(F_h - F_l) > (\mu r F_h - E) - \mu F_l$. As claimed above, we can show that there exists a strategy profile σ^*, and system of belief $\tilde{q}$, such that $(\sigma^*, \tilde{q})$ is a sequential equilibrium. This strategy profile is

$$B_i^* = B^*, i = l, h,\ V^R(p) \leq B^* \tag{A3}$$

$$\rho^*(B) = \begin{cases} 1, \ \forall B \geq B^* \\ 0, \ \forall B < B^*, \end{cases}$$

where $V^R(p) = \mu r[pF_l + (1-p)F_h] - E$. The system of beliefs $\tilde{q}$ supporting this equilibrium is given by

$$\tilde{q}(B) = \begin{cases} p, B = B^* \\ 0, \forall\, V^R(p) < B < B^* \\ p, \forall\, B \leq V^R(p). \end{cases} \tag{A4}$$

It can be verified that $\rho^*(B)$ is optimal given $\tilde{q}$. Both types offering bribe B^* is also optimal given ρ^*. The system of belief given by $\tilde{q}$ above is also consistent.

Let $\mu r F_h - E \leq \mu F_l$, note that this is a sufficient condition for the pooling equilibrium to exist. Consider the pooling equilibrium with $B_h^* = B_l^* = B^* = \mu r(pF_l + (1-p)F_h) - E$. This is the smallest possible equilibrium bribe in a pooling situation. Consider a deviation to bribe B, $\mu r(pF_l + (1-p)F_h) - E > B > \mu r F_l - E$. Equilibrium payoffs of the two types are $U_h^* = U_l^* = -B^*$. As we have done previously, here also we can find the set of mixed best responses by the supervisor so that deviation by the firm would be profitable. It is easy to check that $D(B,h) = \{\rho \in P \mid \rho > \rho_h = \frac{\mu F_h - B^*}{\mu F_h - B} < 1\}$ and $D(B,l) = \{\rho \in P \mid \rho > \rho_l = \frac{\mu F_l - B^*}{\mu F_l - B} < 1\}$. Once again, $D(B,h) \subset D(B,l)$ implying that type l is more likely to have deviated. This is not consistent with the out-of-equilibrium beliefs required to sustain the pooling equilibrium. Similar arguments can be applied to other pooling equilibria.

REFERENCES

Babu, P. G., Kumar, V., & Mehra, P. (2012). *Prosecuting corruption in India: Evidence from Karnataka* (Indian Development Report 2012). New Delhi, India: Oxford University Press.

Bac, M. (1998). The scope, timing, and type of corruption. *International Review of Law and Economics*, *18*(1), 101–120.

Bag, P. K. (1997). Controlling corruption in hierarchies. *Journal of Comparative Economics*, *25*, 332–334.

Baliga, S. (1999). Monitoring and collusion with "soft" information. *Journal of Law, Economics, and Organization*, *15*, 434–440.

Banks, J. S., & Sobel, J. (1987). Equilibrium selection in signaling games. *Econometrica*, *55*, 647–661.

Barron, P., & Olken, B. (2009). The simple economics of extortion: Evidence from trucking in Aceh. *Journal of Political Economy*, *117*, 417–452.

Celik, G. (2009). Mechanism design with collusive supervision. *Journal of Economic Theory*, *144*, 69–95.

Chassang, S., & Ortner, J. (2014). Making collusion hard: Asymmetric information as a counter-corruption measure. Mimeo.

Chatterjee, K., & Samuelson, W. (1983). Bargaining under incomplete information. *Operations Research*, *31*, 835–851.

Cho, I.-K., & Sobel, J. (1990). Strategic stability and uniqueness in signaling games. *Journal of Economic Theory*, *50*, 381–413.

[28] While we specify these particular beliefs, any out-of-equilibrium bribe $B \in (0, \mu r F_h - E)$ along with a sufficiently low belief $\tilde{q}(B) < \frac{\mu r F_h - E - B}{\mu r(F_h - F_l)}$ also supports this equilibrium. However, a similar argument can be used to show that these beliefs do not satisfy $D1$. We are grateful to an anonymous referee for recognizing this possibility.

Fudenberg, D., & Tirole, J. (2000). *Game theory*. Cambridge, MA: MIT Press.

Khalil, F., Lawarrée, J., & Yun, S. (2010). Bribery versus extortion: Allowing the lesser of two evils. *RAND Journal of Economics*, *41*, 179–198.

Kofman, A., & Lawarrée, J. (1996). A prisoner's dilemma model of collusion deterrence. *Journal of Public Economics*, *59*, 117–136.

Laffont, J. J., & Tirole, J. (1993). *A theory of incentive in procurement and regulation*. Cambridge, MA: MIT Press.

Lambsdorff, J. G. (2007). *The institutional economics of corruption and reform: Theory, evidence and policy*. Cambridge, UK: Cambridge University Press.

Lubin, N. (2003). Who is watching the watchdogs? *Journal of International Affairs*, *56*(2), 43–56.

Marjit, S., Rajeev, S., & Mukherjee, D. (2000). Incomplete information as a deterrent to crime. *European Journal of Political Economy*, *16*, 763–773.

Mookherjee, D., & Png, I. P. L. (1995). Corruptible law enforcers: How should they be compensated? *Economic Journal*, *105*, 145–159.

Motta, A. (2009). *Ex-ante and ex-post corruption* (Marco Fanno Working Paper No. 94). University of Padua.

Polinsky, M., & Shavell, S. (2001). Corruption and optimal law enforcement. *Journal of Public Economics*, *81*, 1–24.

Reinganum, J. A., & Wilde, L. (1986). Settlement, litigation, and the allocation of litigation costs. *RAND Journal of Economics*, *17*, 557–566.

Ryvkin, D., & Serra, D. (2012). How corruptible are you? Bribery under uncertainty. *Journal of Economic Behavior and Organization*, *81*, 466–477.

Samuel, A. (2009). Preemptive collusion among corruptible law enforcers. *Journal of Economic Behavior and Organization*, *71*, 441–450.

Shavell, S. (1992). A note on marginal deterrence. *International Review of Law and Economics*, *12*, 345–355.

Tirole, J. (1992). Collusion and the theory of organizations. In J. J. Laffont (Ed.), *Advances in economic theory* (Vol. 2, pp. 151–206). Cambridge, UK: Cambridge University Press.

How to cite this article: Mishra A, Samuel A. Preemptive bribery and incomplete information: Does prior knowledge matter? *Journal of Public Economic Theory*. 2017;19:658–673. https://org.doi/10.1111/jpet.12238