Preannouncement as a Deterrence in a Model of Safety Regulation

Jeong-Yoo Kim and Dong-Hee Koh*

We will examine the role of preannouncement (cheap talk) in a model of safety regulation. It is asserted that if the authority can make a preannouncement, it may transmit credible messages and can induce a more socially desirable level of precaution of the potential injurer even if it is unbinding, because the authority and the agent have some interest in common, that is, to deter accidents. (*JEL* Classification: L59)

I. Introduction

The government often regulates the behavior of the private agents to deter accidents or crimes. As for traffic accidents, for instance, there have been used various forms of the government policy on safety regulation, such as speed limits and regulations of auto safety attributes, vehicle inspection programs, and regulations relating to alcohol consumption, etc..

One interesting observation in reality, however, is that the government sometimes informs the private agents of its intention to regulate beforehand. Then, what is the reason that the government preannounces its intention to regulate drunk driving to the public? Why does the government inform the public of the regulation period to ferret out the illegal piracy of software? Does it have the effect of deterring accidents or crimes? If monitoring incurs some costs, the government may be inclined to renege on the preannounced policy after it has declared to monitor, and nothing can prevent the opportunistic behavior of the government because the preannouncement has no commitment power.

*Department of Economics, Donggk University; School of Economics and Management, Hanyang University. We would like to thank Hyung Bae and an anonymous referee for helpful comments

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Then, is there any good reason that individuals should believe the announcement by the government to monitor? If not in general, under what circumstances can individuals believe the government?

In real life, the language of the government is of much more variety than this. It could be of any form, "I will monitor you this week very strictly." or "Since the road is slippery, do not speed too much." etc.. We will model the various language of the government as "*cheap talk*"[1] and examine the role of cheap talk in the context of safety regulation. Since Crawford and Sobel (1982) showed that cheap talk can be informative if there is some common interest between the players, many authors have demonstrated the effectiveness of cheap talk in some specific settings. (See, for example, Farrell 1987; Farrell and Gibbons 1989; Matthews 1989; Stein 1989; Kim 1996)

In this paper, we consider a model that the government possesses superior information to the potential injurer and try to communicate it to him to induce a more socially desirable level of precaution. We can imagine many situations where the government has an informational advantage over the potential injurer. If it is Christmas tide, a larger proportion of the population would be tempted to drink than usual. This would increase the probability of accident that might happen to a potential injurer while driving. In this case, the government is supposed to possess more accurate estimate on how much the amount of alcohol consumption is increased, or, as the result, how much the probability of traffic accident is increased, according to the statistics. Another example might be found in a small company producing chemicals; It would not pay off for a small company to develop expert knowledge about the dangerous properties of the chemicals it produces, whereas the government wants to acquire this knowledge especially if it is beneficial to others to let them know.

If not all information is shared among players, the resulting outcome is usually far from efficient. It is not surprising that in our model of safety regulation under imperfect information, the potential injuror may take more (or less) precaution than a socially desirable level and the government spends more (or less) resources in monitoring. Then, the natural question that arises is the following; What if a chance is given to the government to inform the potential injurer of its private information?

This paper gives an affirmative answer to this question. We will show that if the authority can make an unbinding announcement—no mat-

[1]Cheap talk means costless, nonbinding, nonverifiable claims

ter what it is concerned with (either its future policy on monitoring or its private information on the state of the nature), a cheap talk equilibrium can be viable where it is taken as serious and can induce a more desirable level of precaution so as to improve the welfare of the private agent as well as the government, because the authority and the agent have some interest in common, that is, to deter accidents.

The economic literature on optimal deterrence has focused on the choice of the less costly regulatory policy to administer in the context of either ex ante safety regulation (Craswell and Calfee 1986) or ex post liability for harm (Brown 1973), or joint use of them (Wittman 1977; Shavell 1984a, 1984b; Kolstad, Ulen and Johnson 1990). In particular, Brown (1973) first showed that strict liability leads to socially optimal behavior while in the absence of liability, potential injurer usually takes underprecaution. Also, Shavell (1984a, 1984b) asserted that liability functions well for inducing socially optimal behavior if the potential injurer possesses superior information over the regulatory authority, but that safety regulation is more attractive than liability if the converse is the case.

In this paper, we introduce "cheap talk (preannouncement)" as one of the government policies and analyze the effect of it on deterring accidents. To our best knowledge, no work so far has addressed the role of preannouncement by the government as a deterrence of accidents. One possible reason for it would be that most literature has considered preannouncement to monitor as identical to the monitoring behavior itself. However, this is the case only if the government can make a binding commitment to monitor. Can we say that preannouncement by the government is really binding? It might be in equilibrium, but not in nature. It is without dispute that reputation effect makes the preannouncement of the government binding in equilibrium since the government is a repeat player. However, if we resort only to reputation effect, there is no room for preannouncement by the government because, even without preannouncement, the government and the private agent could always achieve the most efficient outcome by implicit collusion between them. Even if only the government can be considered as a repeat player, similar argument supports the outcome where the government commits to a particular action by building up its reputation to play the action (Fudenberg, Kreps and Maskin 1990). Therefore, in this paper, we consider an environment where commitment by the government is not feasible either with reputation or without reputation and attempt to provide rationales for preannouncement by the government to be endogenously binding other than mere reputation effect. In this paper, we distinguish two activities of the government, the preannouncement regarding monitoring and the monitoring activity itself, and then analyze the effect of the one on deterring accidents, not the effect of the other and show that cheap talk by the government can reinforce the deterrent effect if it is used jointly with safety regulation and liability. What is good for this regulatory policy is that there are very low administration costs involved with "cheap talk" by the government. Therefore, we can say with confidence that cheap talk is a very cost-efficient way to deter accidents, so that it should be encouraged from the viewpoint of social welfare.

The organization of this paper goes as follows; In Section II, we set up the basic model and its analysis is made in Section III. In Section IV, we perform welfare analysis and provide a numerical example to illustrate our claims. Concluding remarks and caveats follow in Section V.

II. Basic Model

There are one risk neutral potential injurer who engages in an activity involving the risk of accidents and a risk neutral authority who is involved in the regulatory behavior.

The model we consider in this section goes as follows. First, the authority announces some publicly observable, but unbinding message to the private agent before it decides how much it will spend on monitoring. Let $\mathcal{M}$ denote the possible message space that the authority can use. After the government sends the message m from $\mathcal{M}$, it decides how much resources to spend to monitor[2] the activity level of the potential injurer. But the decision by the government is not known to the private agent. If the government spends a on monitoring, the level of precaution that the agent takes is detected with probability $q(a)$. Then, a potential injurer who observed the government's message only chooses a precaution level e to prevent accidents. e determines the probability that an accident occurs, denoted by $p(e, z)$, where z is a measure representing the degree of risk that the society as a whole is exposed to. z is assumed to be private information[3] of the government and to be defined over $[0, 1]$ with the probability density function $f(z)$ which is

[2]In this paper, we use the term "monitoring" as for the input of the accident (the precaution level), while most literature uses it as for the output of the accident (the amount of harm). See Mookherjee and P'ng (1992).

common knowledge. The government can control the activity of the private agent in two ways, ex ante or ex post. First, the government can resort to safety regulation and punish the potential injurer ex ante by levying fines for the unprecautionary activity of the potential injurer. Second, the government can punish the injurer for an accident ex post. If an accident happens, a liability rule can make the injurer liable for the harm done not only to himself but also to others.[4]

Let $L^0(e, z)$[5] be the expected losses when the activity of the potential injurer has not been monitored. Also, let $L^A(e, z)$ and $L^G(e, z)$ be the expected losses of the agent and the government when the activity of the agent has been monitored, respectively. $L^A(e, z)$ may include the damage from a possible accident, fines enforced by monitoring, opportunity costs from nonpecuniary punishment, such as overnight imprisonment, license suspension, etc..

Let C^G, C^A be the total costs of the government and the agent respectively. Then, we have

$$C^G(a, e, z) = \{1 - q(a)\}L^0(e, z) + q(a)L^G(e, z) + e + a \qquad (1)$$

$$C^A(a, e, z) = \{1 - q(a)\}L^0(e, z)^6 + q(a)L^A(e, z) + e \qquad (2)$$

To analyze this model, we will make the following assumptions.

(A1) $a \in X = [0, \infty)$, $e \in Y = [0, \infty)$

(A2) $q(a)$ is twice continuously differentiable with respect to a with $q'(a) > 0$, $q''(a) < 0$

(A3) $L^i(e, z)$ is twice continuously differentiable with respect to e and z with $\{\partial L^i(e, z)/(\partial e)\} < 0$, $\{\partial^2 L^i(e, z)/(\partial e^2)\} > 0$, $\{\partial L^i(e, z)/(\partial z)\} > 0$, $\{\partial^2 L^i(e, z)/(\partial e \partial z)\} < 0$, $\forall e \in Y$, $\forall z \in [0, 1]$, $i = 0, G, A$

(A4) $L^G(e, z) < L^0(e, z) < L^A(e, z)$,[7] $\forall e \in Y$, $\forall z \in [0, 1]$

[3] In many situations, information about risk will require effort to gather or special expertise to evaluate. Then, the government may be in a better position to obtain information or a stronger incentive to do that from a social welfare point of view than the private agent.

[4] We are implicitly assuming that the form of liability is strict.

[5] $L^0(e, z)$ may be understood as the probability of an accident times the magnitude of harm if an accident occurs. A decrease in the precaution level (say, increased speeding) may increase either the probability of an accident or the severity of the damage of an accident.

[6] We rule out the possibility that the injurer would not be sued for harm done or would not be able to pay fully for it. See Shavell (1984b).

[A2] implies that the detection rate is an increasing function of monitoring costs a. The first inequality of [A4] is based on the supposition that ex ante monitoring may have an effect of reducing accidents. (Imagine that if a person is caught driving while under the influence of alcohol, he can be sent home in a cab or deprived of the driver's license.) If this inequality fails to hold, in particular, $L^0(e, z) = L^G(e, z)$, the cost function of the government is reduced to $C^G(a, e, z) = L^0(e, z) + e + a$. Therefore, the government has no reason to choose a positive monitoring, which is unrealistic.[8] The second inequality comes from expected fines when he is monitored ex ante. In this model, monitoring has two conflicting effects on the individual. One is to reduce accidents and the other is to increase expected fines. This inequality says that the fines are set in such a way that the second effect exceeds the first one. If $L^0(e, z) = L^A(\acute{e}, z)$, the individual will not be concerned about being detected for careless behavior, so that ex ante monitoring cannot induce a higher level of precaution. If $L^0(e, z) > L^A(e, z)$, the individual prefers more severe monitoring in the sense that he will take a lower level of precaution with larger a, which is also not realistic.

To simplify the analysis, we replace (A4) with a stronger assumption (A4′).

$$\text{(A4}'\text{)} \quad \frac{L^A(e,z)}{L^0(e,z)} = \eta, \frac{L^G(e,z)}{L^0(e,z)} = \lambda, \forall e \in Y, \forall z \in [0,1], \text{ where } \eta > 1, 0 < \lambda < 1,$$

λ can be interpreted as a measure of the effect that detecting careless behavior could have on reducing accidents and η as a measure of the magnitude of fines.

Suppose the government chooses the best response to a given precaution level of the potential injuror e. Then, the indirect cost function of the government, denoted by $C^{G*}(e, z)$, can be written as

$$C^{G*}(e, z) = C^G(a^*(e, z), e, z),$$

where $a^*(e, z) = \arg\min C^G(a, e, z) = \arg\min \{(1 - q(a))L^0(e, z) + q(a)L^G(e, z) + e + a$

[7]Here, L^G and L^A are assumed to be independent of the size of a. However, a can affect the expected losses of each player through $q(a)$.

[8]Of course, this unrealistc feature can disappear if the government can commit to a positive level of monitoring. However, in this paper, we assume that the government cannot commit to its monitoring behavior. If the government cannot commit, this assumption is essential to obtain a positive monitoring in equilibrium.

Then, we need the following assumptions to simplify our exposition.

(A5) $C^{i*}(e, z)$ is a strictly convex function of e, i.e., $\frac{\partial^2 C^{i*}(e,z)}{\partial e^2} > 0, i = G, A$

(A6) $\frac{\partial^2 C^{i*}(e,z)}{\partial e \partial z} < 0, i = G, A$

(A5) guarantees the unique precaution level that minimizes the expected losses of the government when it responds optimally to e.

III. Analysis

In this section, we will analyze the model. As the solution concept, we will adopt the Bayesian Perfect Equilibrium.

Let $e^G(z)$, $e^A(z)$ be the precaution level that the government or the potential injurer respectively prefers most when private information of the government is given by z, given that the government responds optimally to e, i.e., $e^G(z) = \arg\min C^{G*}(e, z)$, $e^A(z) = \arg\min C^{A*}(e, z) = \arg\min C^A(a^*(e, z), e)$. Then, the next lemma follows.

Lemma 1
(i) $e^G(z)$ is strictly increasing in z, i.e., $\{de^G(z)\}/dz > 0$ (ii) $e^A(z)$ is strictly increasing in z, i.e., $\{de^A(z)\}/dz > 0$

Proof: (i) direct from (A5) and (A6) (ii) can be proved similarly

This lemma implies that for a given value of z, both players prefer a specific level of precaution than others. That is, it shows that this model satisfies the sorting condition in the cheap talk game by Crawford and Sobel (1982).

Lemma 2
Suppose that z is known to both players and that the government responds optimally to e. Then, the precaution level that is favorite to the government is lower than to the potential injuror for any z, i.e., $e^G(z) < e^A(z)$, $\forall z \in [0, 1]$

Proof: See the appendix.

This lemma shows that interests of the two players do not coincide.

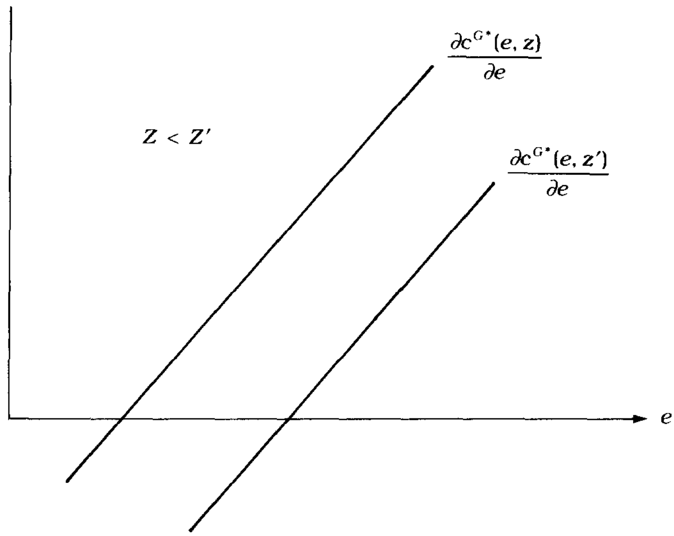

FIGURE 1

However, this may be quite counterintuitive. This overprecaution result comes from the fact that the potential injurer is expected to pay a large fine for his careless behavior.

***Corollary* 1**

Let $\mathcal{E}$ be the set of the equilibrium precaution level. Then, $\mathcal{E}$ is finite.

Proof: See the appendix.

This corollary implies that there cannot exist a fully separating equilibrium in this game. Then, our theorem follows.

Theorem 1

There exist partially separating equilibria, where the government sends one of the finite number of messages $m_k \in \mathcal{M}$, $\forall z \in I_k$, where $I_k = [z_{k-1}, z_k)$, $k = 1, \ldots, n-1$, $I_n = [z_{n-1}, z_n]$, $z_0 = 0$, $z_n = 1$ and after observing the message m_k, the agent updates his belief to I_k and then the government and the agent play a Nash outcome, $a(z) = a_k(z)$, $e = e_k$, where $(a_k(z), e_k)$ is a Nash Equilibrium of the original game with belief updated to I_k.

Proof: See the appendix.

It is a well-known fact that there exists a babbling equilibrium where cheap talk is not taken as serious in every cheap talk game. The above theorem tells that this cheap talk game has another equilibrium, a communicative equilibrium where the potential injurer takes the government's cheap talk as serious. We will focus our attention on this equilibrium for our analysis henceforth.

Can we say that welfare is always improved by cheap talk in this game? We cannot offer a complete answer to this question in this model with general functional forms, but in the next section we will provide a partial answer for it.

IV. Welfare Analysis

In this section, we address the issue on welfare to see whether efficiency is improved with cheap talk by the government.

Letting $(a^*(z), e^*)$ be a babbling equilibrium which corresponds to the one without cheap talk,[9] $(a^*(z), e^*)$ satisfies

$$a^*(z) = \arg\min C^G(a, e^*, z), \tag{3}$$

$$\begin{aligned} e^* &= \arg\min E[C^A\{a^*(z), e, z, \}] \\ &= \arg\min \int_0^1 [\{1 - q(a^*(z))\}L^0(e^*, z) + q\{a^*(z)\}L^A(e^*, z) + e]f(z)dz. \end{aligned} \tag{4}$$

Let $(a_k(z), e_k)_{k=1}^n$ be an equilibrium with cheap talk. Also, let $e(\underline{z}, \bar{z})$ be the equilibrium precaution level when the agent has updated his belief to $[\underline{z}, \bar{z}]$. Then, since $e(\underline{z}, \bar{z})$ is increasing in both argument, it is clear that $e_j \leq e^* \leq e_{j+1}$ for some j $(0 \leq j \leq n-1)$. If $e^* = e_j$ or e_{j+1}, i.e., e^* is one of the equilibrium precaution levels at the cheap talk equilibrium, it is obvious that both the government and the agent are made better off by cheap talk.

Now, suppose that $e_j < e^* < e_{j+1}$ for some j. It is clear that ex post the government can be made worse off with cheap talk, if z is realized in a neighborhood of z_j. This is because $C^{G^*}(e_j, z_j) = C^{G^*}(e_{j+1}, z_j)$ and $e_j < e^* < e_{j+1}$ yield $C^{G^*}(e_j, z_j) > C^{G^*}(e^*, z_j)$ for z_j. However, in this case, too, the government ex ante can be made better off with cheap talk if

[9]We are assuming that the babbling equilibrium is a separating equilibrium. However, we can easily show that there exists no pooling equilibria in a game without cheap talk. For a rigorous analysis for the model without cheap talk, see Kim and Koh (1994).

$$\sum_{k=1}^{k=n} \int_{z_{k-1}}^{z_k} C^G\{a_k(z), e_k, z\} f(z)dz < \int_{z_0}^{z_n} C^G\{a^*(z), e^*, z\} f(z)dz, \tag{5}$$

or equivalently,

$$\sum_{k=1}^{k=n} \int_{z_{k-1}}^{z_k} C^{G^*}(e_k, z) f(z)dz < \int_{z_0}^{z_n} C^{G^*}(e^*, z) f(z)dz. \tag{6}$$

Since $C^{G^*}(e_j, z_j) = C^{G^*}(e_{j+1}, z_j)$ and $\varepsilon_j < e^* < e_{j+1}$, we have $C^{G^*}(e^*, z_j) < C^{G^*}(e_k, z_j)$, $k = j, j+1$, $C^{G^*}(e_j, z_{j-1}) < C^{G^*}(e^*, z_{j+1})$, $C^{G^*}(e_{j+1}, z_{j+1}) < C^{G^*}(e^*, z_{j+1})$. Also, from continuity of $C^{G^*}(e, z)$ in z, $\forall e$, there exist $\tilde{z}_{j-1} \in (z_{j-1}, z_j)$ such that $\forall z \in [z_{j-1}, \tilde{z}_{j-1}]$, $C^{G^*}(e_j, z) \le C^{G^*}(e^*, z)$ and $\forall z \in [\tilde{z}_{j-1}, z_j)$, $C^{G^*}(e_j, z) \ge C^{G^*}(e^*, z)$, and $\tilde{z}_{j+1} \in (z_j, z_{j+1}]$ such that $\forall z \in [z_j, \tilde{z}_{j+1}]$, $C^{G^*}(e_{j+1}, z) \le C^{G^*}(e^*, z)$ and $\forall z \in [\tilde{z}_{j+1}, z_{j+1}]$, $C^{G^*}(e_{j+1}, z) \le C^{G^*}(e^*, z)$. Therefore, (6) is reduced to

$$\int_{\tilde{z}_{j-1}}^{z_j} \{C^{G^*}(e_j, z) - J(z)\} f(z)dz + \int_{z_j}^{\tilde{z}_{j-1}} \{C^{G^*}(e_{j+1}, z) - J(z)\} f(z)dz <$$

$$\sum_{k \ne j\ j+1} \int_{z_{k-1}}^{z_k} \{J(z) - C^{G^*}(e_k, z)\} f(z)dz + \int_{z_j}^{\tilde{z}_{j-1}} \{J(z) - C^{G^*}(e_{j+1}, z)\} f(z)dz + \tag{7}$$

$$\int_{\tilde{z}_{j+1}}^{z_{j+1}} \{J(z) - C^{G^*}(e_{j+1}, z)\} f(z)dz,$$

where $J(z) = C^{G^*}(e^*, z)$. Since $C^{G^*}(e_k, z) < J(z)$, $\forall z \in [z_{k-1}, z_k)$, $k \ne j, j+1$, all terms in (7) are positive. Therefore, we can say that the government tends to be better off with preannouncement as the cheap talk equilibrium becomes more informative, i.e., n is larger. However, if n is small enough, we cannot exclude the possibility that the government is worse off with cheap talk even ex ante. We can make similar reasoning for the agent's welfare by observing that $e_j < e^A(z_j) < e_{j+1}$.

Before we close this section, we will conduct simulations to check our claim that there may exist cheap talk equilibria and to see if welfare can be improved with cheap talk.

We assume that z is uniformly distributed with $f(z) = 1$ over $[0, 1]$. Let $q(a) = a/(a+1)$, $L(e, z) = (z+1)/(e+1)L$. Then, from (3) and (4),

$$(e^* + 1)^2 + \frac{3}{2}(2\sqrt{2} - 1)(\eta - 1)\sqrt{\frac{L}{1-\lambda}}\sqrt{e^* + 1} = \frac{3}{2}\eta L$$

$$a^*(z) = -1 + \sqrt{\frac{(1-\lambda)(z+1)}{e^* + 1}L}$$

Letting $L = 10$, $\eta = 2$ and $\lambda = 0.8$, the equilibrium precaution level of the potential injurer when there is no cheap talk is $e^* = 2.671973$ and $a^*(z)$

$= -1 + 0.738915\sqrt{z+1}$. Then, from (1) and (2), the equilibrium (ex ante) expected costs are

$$\int_0^1 C^{G^*}dz = e^* - 1 + \frac{3}{2}\frac{\lambda L}{e^*+1} + \frac{4}{3}(2\sqrt{2}-1)\sqrt{\frac{(1-\lambda)L}{e^*+1}} = 6.739180$$

$$\int_0^1 C^{A^*}dz = e^* + \frac{3}{2}\frac{\eta L}{e^*+1} + \frac{2}{3}(2\sqrt{2}-1)\sqrt{\frac{(1-\lambda)L}{e^*+1}} = 11.741573$$

Now, suppose that cheap talk is allowed. Then, from Theorem 1,

$$(z_k - z_{k-1})(e_k+1)^2 + \frac{3}{2}\left\{(z_k+1)^{\frac{3}{2}} - (z_{k-1}+1)^{\frac{3}{2}}\right\}(\eta-1)\sqrt{\frac{L}{1-\lambda}}\sqrt{e_k+1}$$

$$= \frac{1}{2}\{(z_k+1)^2 - (z_{k-1}+1)^2\}\eta L,$$

$$k = 1,\ldots,n$$

$$e_k - 1 + \lambda L\frac{z_k+1}{e_k+1} + 2\sqrt{\frac{(1-\lambda)(z_k+1)L}{e_k+1}}$$

$$= e_{k+1} - 1 + \lambda L\frac{z_k+1}{e_{k+1}-1} + 2\sqrt{\frac{(1-\lambda)(z_k+1)L}{e_{k+1}+1}},$$

$$k = 1,\ldots,n.$$

Since we have one degree of freedom to determine z_k's as observed in Crawford and Sobel (1982), we may set $z_1 = 0.2$ without loss of generality. Then, it can be easily observed that $n = 2$, $e_1 = 2.019519$ and $e_2 = 3.141102$, yielding $\int_0^1 C^{G^*}\,dz = 6.716529$ and $\int_0^1 C^{A^*}\,dz = 11.427950$). Therefore, we can see that with cheap talk, the welfare of the government can be improved and the welfare of the potential injurer as well.

V. Conclusion

In this paper, we have provided a general model incorporating safety regulation, liability and preannouncement by the government, and shown that cheap talk by the authority can transmit some information credibly on the riskiness of the society as a whole or what the authority will do, even if it is unbinding and can complement safety regulation and liability in the sense that it can reduce the accidents by inducing more precaution when social risk is high, if it is jointly used with them.

Although this paper assumes that the government possesses private information on the social risk on z, the analysis and the implication will not be made significantly different by assuming private information on the monitoring technology $q(a)$ instead i.e., on what will be the detection probability when the government spends resources a on monitoring.

However, this model is restrictive in the sense that a fine schedule is assumed to be given, not a choice variable of the government. Hence, we have not been able to address the argument of Becker (1968) on the maximum permissible fines, saying that since fines are transfer payments, while ex ante monitoring is costly, society should set all fines at the maximum possible. It will be a promising avenue to pursue a model of the endogenized fine schedule. Also, the relationship between the government and the private agent is repeated all the time. That is, preannouncements are not made only once and for all, but rather made repeatedly. Then, the private agent is endowed with the ability to check the accuracy of what the government announced. Therefore, it will be an interesting challenge to see whether and if so, when repeated play makes preannouncements more credible.

Appendix: Proofs

Proof of Lemma 2

$e^G(z)$ and $e^A(z)$ are defined as satisfying the followings respectively,

$$\phi^G(e) \equiv -q'(a^*)\frac{\partial a^*}{\partial e}L^0 + \{1-q(a^*)\}L_1^0 + q'(a^*)\frac{\partial a^*}{\partial e}L^G + q(a^*)L_1^G + 1 + \frac{\partial a^*}{\partial e} = 0 \quad \text{(A1)}$$

$$\phi^A(e) \equiv -q'(a^*)\frac{\partial a^*}{\partial e}L^0 + \{1-q(a^*)\}L_1^0 + q'(a^*)\frac{\partial a^*}{\partial e}L^A + q(a^*)L_1^A + 1 = 0 \quad \text{(A2)}$$

Let $\Phi(e) \equiv \phi^G(e) - \phi^A(e) = q'(a^*)\,(\partial a^*)/(\partial e)\,(L^G - L^A) + q(a^*)(L_1^G - L_1^A) + (\partial a^*)/(\partial e)$. On the other hand, we have

$$-q'(a^*)L^0 + q'(a^*)L^G + 1 = 0$$

Therefore, $q'(a^*) = 1/(L^0 - L^G)$, $(\partial a^*)/(\partial e) = \{-q'(L_1^0 - L_1^G)\}/\{q''(L^0 - L^G)\}$. Substituting these, we get

$$\Phi(e) = \frac{-L_1^0\{(1-\eta)q' + (1-\lambda)(\eta-\lambda)qq'L^0\}}{(1-\lambda)q''L^0} > 0$$

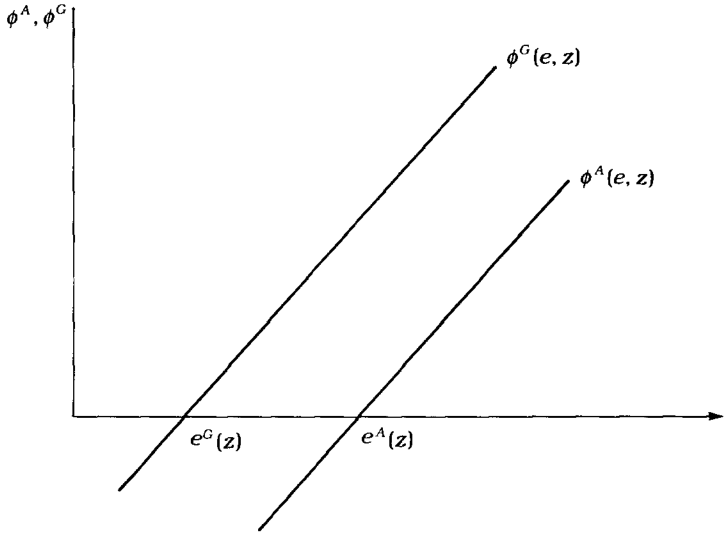

FIGURE 2

Therefore, $\phi^G(e) > \phi^A(e)$, $\forall z \in [0, 1]$. Also, we have $\phi^G/\partial e$, $\phi^A/\partial e > 0$ from (A5), which means that $e^G(z) < e^A(z)$, $\forall z \in [0, 1]$.

Q.E.D.

Proof of Corollary 1

Let $\delta \equiv \min\{e^A(z) - e^G(z) \mid z \in [0, 1]\}$. Then, δ is well-defined and $\delta > 0$ from the compactness of [0, 1] and Lemma 2. Let e, e' ($e < e'$) be any equilibrium precaution level induced by z, z'. Then, clearly, $z < z'$. Also, we have $C^{G*}(e, z) < C^{G*}(e', z)$ and $C^{G*}(e, z') > C^{G*}(e', z')$. Since $C^{G*}(e, z)$ is continuous in z, $\forall e \in Y$, $C^{G*}(e, \bar{z}) = C^{G*}(e', \bar{z})$, for some $\bar{z} \in [z, z']$ and e (e') can be induced only by $z \le \bar{z}$ ($z \ge \bar{z}$), respectively. Then, by virtue of Lemma 1, we can show that $e < e^G(\bar{z}) < e'$ and $e < e^A(\bar{z}) < e'$. First, it is obvious that $e < e^G(\bar{z}) < e'$. For the second part, if $e^A(z') \le e'$, it is clear since $e^A(\bar{z}) < e^A(z') \le e'$. If e' < $e^A(z')$, e' cannot be an equilibrium strategy because $\forall z \ge \bar{z}$, $\{\partial C^A(a', e', z)\}/(\partial e) = \{\partial C^{A*}(e', z)\}/(\partial e) < 0$ for the equilibrium strategy a' associated with e'. Then, $e' - e > e^A(\bar{z}) - e^G(\bar{z}) \ge \delta$, $\forall e, e' \in \mathcal{E}$. Therefore, $\mathcal{E}$ should be finite.

Q.E.D.

Proof of Theorem 1

Let $z_0, \ldots, z_n$ satisfy $C^{G*}(e_k, z_k) = C^{G*}(e_{k+1}, z_k)$, $k = 1, \ldots, n - 1$, $z_0 = 0$, z_n

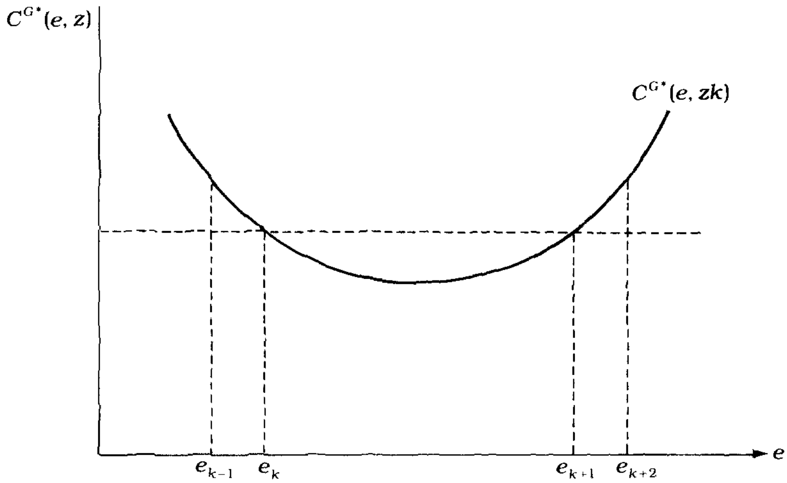

Figure 3

= 1, where e_k is an equilibrium strategy of the agent given his belief I_k. This relation gives a difference equation in z'_k's with the initial condition and terminal condition. Then, we can easily see that there is at least one solution for $\{z_k\}_{k=0,1,\ldots,n}$.[10] Now, we have to check the incentive compatibility.

(i) The government sends m_k if $z \in I_k$.

First, it is clear that $e_1 < e_2 < \ldots < e_n$. We have $C^{G^*}(e_k, z_k) = C^{G^*}(e_{k+1}, z_k)$. Since $C^{G^*}(e, z)$ is convex with respect to e, $\forall z$, $C^{G^*}(e_k, z_k) = \min_{1 \le i \le n} C^{G^*}(e_i, z_k)$. Then, from (A6), it follows that $\forall z \in I_{k+1}$,

$$C^{G^*}(e_k, z) - C^{G^*}(e_j, z) \le C^{G^*}(e_k, z_k) - C^{G^*}(e_j, z_k) \le 0$$
$$C^{G^*}(e_k, z) - C^{G^*}(e_l, z_k) \le C^{G^*}(e_k, z_{k+1}) - C^{G^*}(e_l, z_{k+1}) \le 0$$
$$\text{where } \quad 0 \le j < k < l \le n$$

(ii) The players play $(a_k(z), e_k)$ after observing m_k.

Since the potential injurer updates his belief to I_k after he observes m_k, it is clear that $(a_k(z), e_k)$ is the best responses of the government and the agent to each other.

Q.E.D.

[10]Also, we can easily notice that the values of z_k are not uniquely determined. Actually, Crawford and Sobel (1982) showed that there is n^*, a maximum of such n and that for all $n \le n^*$, there exists a partially pooling equilibrium.

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