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Information Acquisition and Disclosure of Environmental Risk

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Abstract:
Firms often invest resources in acquiring scientific evidence to evaluate the actual (more accurate) risk (i.e., the probability of occurrence) of any potential environmental hazards that might result from their own production processes and use this information in taking optimal preventive measures. In a symmetric duopoly where the acquired information about environmental risk is observed privately by the firms, I show that requiring firms to publicly report this information increases the strategic incentive of firms to invest in information acquisition. However, the net expected environmental damage of an investing firm is lower if there is no public disclosure.

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1 Introduction

The information structure of society about the relationship between the natural environment and economic activities is an important factor affecting the perception of environmental risk. Such information determines the incentives of stakeholders and eventually the incentives of society to regulate the actions of agents that contribute to environmental risk. The existing literature in environmental economics assumes that firms are more likely to have better and private information about their own environmental performance as well as the likelihood of any future environmental disaster caused by their own production process. Thus, the literature primarily focuses on the incomplete information problem between firms and regulators or between firms and consumers[1]. However, a firm might lack appropriate scientific evidence to predict an almost accurate probability of occurrence of an environmental accident due to its own production process[2]. In this paper, I refer the probability of occurrence of an environmental accident/disaster associated with a firm's production process as the environmental risk of the firm. Moreover, strict liability rules require firms to pay a penalty once the environmental damage becomes observable (in the future). Thus, one can argue that firms may have a strategic incentive to invest in scientific research to evaluate their own environmental risk and consequently, decide whether to adopt necessary preventive measures.

If firms invest in scientific research to accurately evaluate their own environmental risks then an immediate question is whether the policy makers should make it mandatory for firms to truthfully disclose such acquired information. There are few mandatory policies (such as Toxic Release Inventory (USA), Environmental Reporting Decree (the Netherlands), Green Accounts (Denmark), Pollutant Release and Transfer Register (UK) etc.) that make firms truthfully disclose their environmental performances. Moreover, concerned shareholders often pressurize firms for sufficient environment (climate) risk disclosure, as stock prices tend to crash once an environmental disaster becomes observable. The US Securities and Exchange Commission (SEC) was recently "criticized for lax enforcement of climate risk disclosure" under federal security laws. The main contribution of this paper is to critically examine the role of more effective and stringent implementation of mandatory disclosure laws to promote strategic environmental risk evaluation by firms.

I consider a market where two *ex ante* identical firms produce physically homogenous products and engage in quantity competition a la Cournot. I find that both firms, prior to choosing output and preemptive care to avoid environmental damage, may strategically invest in research to evaluate their actual risk of future environmental damage (associated with their own production process). Both firms have *higher* strategic incentive to invest under mandatory disclosure laws when firms are subject to public disclosure of their evaluated environmental risk, compared to the situation where such information remains privy to the individual firms [3]. Surprisingly, I find a trade-off between a firm's strategic incentive of environmental risk evaluation and the expected environmental damage. Though, better scientific information about the likelihood of potential future

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damage could be beneficial (since it allows firms to fine tune their prevention efforts), strategic risk evaluation and disclosure also induce higher output, and consequently, more pollution. Therefore, for a regulatory authority that primarily focuses on emission reduction, implementation of a mandatory disclosure rule of environmental risk might not be a good choice, because there is a rebound effect; the information about rival's evaluated environmental risk encourages the firm to produce more output and this, in turn, creates higher expected environmental damage.

Our paper builds on the literature of environmental performance disclosure in environmental economics and accounting. However, most of the papers focus on the issue of voluntary risk disclosure by firms[4]. Critics argue that firms often tend to misreport their environmental performance; there are, in fact, plenty of empirical evidence to support this accusation of "green washing". Note that the issue of strategic (voluntary disclosure) is beyond the scope of this paper; here, I consider two exogenously imposed information structures, namely *truthful mandatory disclosure* and *no disclosure*. Unfortunately, the existing mandatory disclosure policies do not necessarily get a clear pass either. The environmental accounting literature provides mixed evidence on the role and effectiveness of mandatory disclosure policies. Peters and Romi (2013) critically examine the effectiveness of existing mandatory environmental accounting disclosure required by Environmental Protection Agency (EPA) in the United States. Mobus (2005) finds that the mandatory environmental performance disclosure in financial reports has helped firms in the US oil refining industry to improve their subsequent environmental compliance (between 1992 and 1994). There is a substantial body of literature in empirical environmental economics that critically evaluates the performance of Toxic Release Inventory[5]. In this paper, I assume that the firms always truthfully report their environmental risks under mandatory disclosure laws[6] so that I can focus primarily on the strategic interactions among firms (i.e., firms' strategic incentives to invest in environmental risk evaluation). Further, unlike this paper, most of the existing literature assumes that firms do not need to make any investment in research because firms already possess all the necessary scientific information to evaluate their environmental risks. To the best of my knowledge, this paper is one of the first attempts to analyze firm's *strategic incentive* to invest in the evaluation of environmental risk (since the firms currently lack the required scientific evidence) under exogenously imposed information structures viz., mandatory disclosure as well as no disclosure. This adds to the debate of need for more stringent and effective mandatory disclosure laws by public authorities to encourage strategic preemptive care by firms against environmental disasters.

The paper is organized as follows. The next section depicts the basic model. In Section 3, I study a firm's strategic incentive to invest in environmental risk evaluation under mandatory disclosure laws. Section 4 examines firms' investment behaviors when there is no disclosure rule and discusses the relevant policy implications. The final section concludes.

2 Model

I consider a market where two *ex ante* symmetric firms produce a physically homogeneous good at a constant marginal production cost c. The firms face an inverse linear demand $p = a - \sum_{j=1}^{2} q_j$ where q_j is the output produced by firm j for all $j = 1, 2$. Firms strategically compete in terms of quantities. The production technologies in use[7] may cause an environmental damage of λq_j in the future with a positive *ex ante* strictly positive probability denoted by μ_j. Here $\lambda > 0$ is the constant marginal damage per unit of output of a firm. I assume that μ_j is an independently and identically distributed random variable for all $j = 1, 2$ and it follows a uniform distribution $U \sim [0, \overline{\mu}]$ where $\overline{\mu} \in (0, 1]$. I refer μ_j as the environmental risk of firm j in the rest of the paper. To begin with, firms do not know the actual value of their own risk; however, the probability distribution of the risk is common knowledge among firms.

Firms are subject to some liability rule; firm j will have to pay a compensation equal to $t\lambda q_j$, if the damage becomes observable in the future. Here $t > 0$ is defined as the *liability rate* per unit of damage[8]. Firms strategically decide to reduce the marginal damage at the rate $\alpha_j > 0$. I assume that the total cost of such preventive action is $\frac{(\alpha_j q_j)^2}{2}$.

The timeline is as follows. First, nature independently draws the type μ_j (i.e., environmental risk) of the production technology of each firm from a common uniform distribution $U \sim [0, \overline{\mu}]$ where $\overline{\mu} \in (0, 1]$, and this is common knowledge. The realization of a firm's type, denoted by $\widehat{\mu}_j$, remains unknown to the firm as well as to the rival. In the next stage, each firm (strategically) invests resources to acquire scientific evidence to evaluate the actual environmental risk of its own existing production technology. In other words, firms strategically decide whether to invest a fixed amount F to find out the actual value of the risk of future environmental damage. If firm j invests then it finds out its actual environmental risk i.e., $\widehat{\mu}_j$ for sure. I consider two exogenously given information regimes; under *mandatory disclosure* (MD) firms reveal their own risks to each other, whereas such information remains privy to the firm under *no disclosure* (ND) . Under the latter information structure, I separately examine the case where the firms manage to observe each other's investment decisions as well as the state where such decisions are not at all observable. Finally, the firms simultaneously choose their own output and degree of prevention per unit of output. I solve the three-stage full information (in Section 3) as well as incomplete information Bayesian game (in Section 4) by backward induction.

There are three possibilities after firms decide whether to invest, namely (1) both firms invest (II) , (2) only one firm invests (denoted by NI when the firm does not invest and by IN if the rival does not invest) and (3) no firm invests (NN). I use superscript on variables to denote the disclosure regime and subscripts to specify one of the three possibilities after the investment stage. For example, $\pi_{j,II}^{MD}$ denotes the equilibrium profit of a firm j (after the second stage) when both firms invest (II) and reveal their environmental risks to each other under mandatory disclosure (MD).

In this paper, the *unilateral incentive* (UI) to invest in risk evaluation is defined as the difference between *ex ante* expected profit of an investing firm when the rival does not invest and the expected profit of the firm when both firms do not invest whereas the *reciprocal incentive* (RI) to invest is the *ex ante* expected profit of an investing firm when both firms invest minus the *ex ante* expected profit of a non-investing firm when the rival invests. If $UI \geq 0$ then a firm has an incentive to invest in the research of its own environmental risk evaluation even if the rival does not invest; moreover if $RI \geq 0$ then a firm has reciprocal incentive to invest. In equilibrium, at least one firm invests if the unilateral incentive to invest is at least as high as the fixed cost $(UI \geq F)$, and both firms invest when the reciprocal incentive to invest exceeds the fixed cost of investment $(RI \geq F)$.

3 Mandatory Disclosure

In this section, I examine whether firms have any strategic incentive to invest in scientific research to evaluate its own environmental risk when firms are subject to mandatory public disclosure of such information. To solve the three-stage (full information) game backwards, I consider the aforementioned three possible cases that can arise after the strategic investment decisions by the firms and subsequent full disclosure of the findings (evaluated environmental risks).

Case (1): If **both firms invest**, each firm j for all $j = 1, 2$ reveals its own evaluated risk $\widehat{\mu}_j$ to the rival firm $-j$ for all $-j = 1, 2$ where $j \neq -j$. Firm j maximizes the profit

$$\max_{q_j, \alpha_j} \left[\left(a - q_j - q_{-j}\right) q_j - c q_j - \widehat{\mu}_j t \left(\lambda - \alpha_j\right) q_j - \frac{\left(\alpha_j q_j\right)^2}{2} - F \right] \tag{1}$$

with respect to q_j and α_j for any possible realization of environmental risks $\left(\widehat{\mu}_j, \widehat{\mu}_{-j}\right)$. The equilibrium output and prevention rate of an investing firm are given by

$$q_{j,II}^{MD}\left(\widehat{\mu}_j, \widehat{\mu}_{-j}\right) = \frac{\left(a - c - t\lambda\left(2\widehat{\mu}_j - \widehat{\mu}_{-j}\right)\right)}{3} \text{ and } \alpha_{j,II}^{MD}\left(\widehat{\mu}_j, \widehat{\mu}_{-j}\right) = \frac{3t\widehat{\mu}_j}{\left(a - c - t\lambda\left(2\widehat{\mu}_j - \widehat{\mu}_{-j}\right)\right)} \tag{2}$$

respectively. Since the firms are symmetric the rival (firm $-j$) has the same equilibrium output and rate of prevention. I get the equilibrium profit $\pi_{j,II}^{MD}\left(\widehat{\mu}_j, \widehat{\mu}_{-j}\right)$ by substituting eq. (2) into eq. (1) . The *ex ante* (prior to a firm's investment decision) expected profit of firm j is given by

$$\begin{aligned} E\left(\pi_{j,II}^{MD}\left(\widehat{\mu}_j, \widehat{\mu}_{-j}\right)\right) &= \frac{1}{\overline{\mu}} \int_0^{\overline{\mu}} \frac{1}{\overline{\mu}} \int_0^{\overline{\mu}} \left[\pi_{j,II}^{MD}\left(\widehat{\mu}_j, \widehat{\mu}_{-j}\right)\right] d\widehat{\mu}_{-j} d\widehat{\mu}_j \\ &= \frac{(a-c)^2 - \overline{\mu} t\lambda (a-c) + \overline{\mu}^2 t^2 \left(\frac{2}{3}\lambda^2 + \frac{3}{2}\right)}{9} - F \end{aligned} \tag{3}$$

Case (2): Suppose only **one firm invests** i.e., firm j invests but the rival $-j$ does not. Firm j publicly discloses its environmental risk. Thus, firm $-j$ knows the exact value of μ_j but it does not know its own actual risk $\widehat{\mu}_{-j}$. The investing firm j's maximization problem is given by eq. (1), while non-investing firm $-j$ solves

$$\max_{q_{-j}, \alpha_{-j}} \left[\left(a - q_{-j} - q_j\right) q_{-j} - c q_{-j} - \left(\frac{1}{\overline{\mu}} \int_0^{\overline{\mu}} \mu_{-j} d\mu_{-j}\right) t \left(\lambda - \alpha_{-j}\right) q_{-j} - \frac{\left(\alpha_{-j} q_{-j}\right)^2}{2} \right]. \tag{4}$$

The equilibrium market outcomes are[9]

$$q^{MD}_{j,IN}\left(\widehat{\mu}_j,.\right) = \frac{(a-c)-t\lambda\left(2\widehat{\mu}_j-\frac{\overline{\mu}}{2}\right)}{3}, \alpha^{MD}_{j,IN}\left(\widehat{\mu}_j,.\right) = \frac{3\widehat{\mu}_j t}{\left[(a-c)-t\lambda\left(2\widehat{\mu}_j-\frac{\overline{\mu}}{2}\right)\right]}$$
$$q^{MD}_{-j,NI}\left(\widehat{\mu}_j,.\right) = \frac{(a-c)-t\lambda\left(\overline{\mu}-\widehat{\mu}_j\right)}{3}, \alpha^{MD}_{-j;NI}\left(\widehat{\mu}_j,.\right) = \frac{3\overline{\mu}t}{2\left[(a-c)-t\lambda\left(\overline{\mu}-\widehat{\mu}_j\right)\right]} \tag{5}$$

The *ex ante* expected profits of the investing and non-investing firm are given by

$$E(\pi^{MD}_{j,IN}\left(\widehat{\mu}_j,.\right)) = \frac{1}{\overline{\mu}}\int_0^{\overline{\mu}} \pi^{MD}_{j,IN}\left(\widehat{\mu}_j,.\right) d\widehat{\mu}_j = \frac{(a-c)^2-\overline{\mu}t\lambda\,(a-c)+\overline{\mu}^2t^2\left(\frac{7}{12}\lambda^2+\frac{3}{2}\right)}{9} - F \tag{6}$$

$$\text{and } E\left(\pi^{MD}_{-j,NI}\left(\widehat{\mu}_j,.\right)\right) = \frac{1}{\overline{\mu}}\int_0^{\overline{\mu}} \pi^{MD}_{-j,NI}\left(\widehat{\mu}_j,.\right) d\widehat{\mu}_j = \frac{(a-c)^2-\overline{\mu}t\lambda\,(a-c)+\overline{\mu}^2t^2\left(\frac{\lambda^2}{3}+\frac{9}{8}\right)}{9} \tag{7}$$

Case (3): Since **no firm invests**, both firms remain unaware of the actual value of the risk of future environmental damage. Firm j maximizes the profit

$$\max_{q_j,\alpha_j}\left[\left(a-q_j-q_{-j}\right)q_j - cq_j - \left(\frac{1}{\overline{\mu}}\int_0^{\overline{\mu}}\mu_j d\mu_j\right)t\left(\lambda-\alpha_j\right)q_j - \frac{\left(\alpha_j q_j\right)^2}{2}\right] \tag{8}$$

The equilibrium output and rate of prevention of a non-investing firm are

$$q^{MD}_{j,NN}\left(.,.\right) = \frac{(a-c-\frac{\overline{\mu}}{2}t\lambda)}{3} \text{ and } \alpha^{MD}_{j,NN}\left(.,.\right) = \frac{3t\overline{\mu}}{2(a-c-\frac{\overline{\mu}}{2}t\lambda)} \tag{9}$$

Since the firms are symmetric the rival (firm $-j$) has the same equilibrium output and rate of prevention. The *ex ante* expected profit is given by

$$E\left(\pi^{MD}_{j,NN}\left(.,.\right)\right) = \pi^{MD}_{j,NN}\left(.,.\right) = \frac{(a-c)^2-\overline{\mu}t\lambda\,(a-c)+\overline{\mu}^2t^2\left(\frac{\lambda^2}{4}+\frac{9}{8}\right)}{9} \tag{10}$$

The *unilateral* (UI) and *reciprocal* (RI) incentives of a firm to invest in the research under public disclosure are

$$UI^{MD}_j = E(\pi^{MD}_{j,IN}\left(\widehat{\mu}_j,.\right)) - \pi^{MD}_{j,NN}\left(.,.\right) = \frac{\overline{\mu}^2t^2}{3}\left(\frac{\lambda^2}{9}+\frac{1}{8}\right) - F \tag{11}$$

$$RI^{MD}_j = E\left(\pi^{MD}_{j,II}\left(\widehat{\mu}_j,\widehat{\mu}_{-j}\right)\right) - E\left(\pi^{MD}_{j,NI}\left(.,\widehat{\mu}_{-j}\right)\right) = \frac{\overline{\mu}^2t^2}{3}\left(\frac{\lambda^2}{9}+\frac{1}{8}\right) - F \tag{12}$$

Note that the unilateral incentive to invest in the risk evaluation is exactly equal to that of the reciprocal incentive. The following proposition depicts the investment equilibrium under mandatory disclosure.

Proposition 1 *Under mandatory disclosure rule, both firms invest in research to evaluate future environmental risk if the fixed cost of investment does not exceed a certain threshold i.e.,*$F \leq F^{MD} = \frac{\overline{\mu}^2t^2}{3}\left(\frac{\lambda^2}{9}+\frac{1}{8}\right)$; *otherwise, no firm invests.*

The proof follows by simply comparing eqs (11) and (12). An alternative interpretation of the proposition is that both firms invest in research to evaluate future environmental risk for any liability rate

$$t \geq t^{MD} = \sqrt{\frac{3F}{\overline{\mu}^2\left(\frac{\lambda^2}{9}+\frac{1}{8}\right)}} \text{ when } F > 0 \tag{13}$$

and for all possible liability rate if $F = 0$. If the liability rate is sufficiently low i.e., $t < t^{MD} = \sqrt{\frac{3F}{\overline{\mu}^2\left(\frac{\lambda^2}{9}+\frac{1}{8}\right)}}$ for strictly positive fixed cost $(F \neq 0)$, then, in equilibrium, no firm invests, to find out the actual risk of a future environmental damage.

4 No Disclosure

In the absence of any mandatory disclosure laws as well as any credible voluntary disclosure mechanism, which seems to fit the reality well, the evaluated environmental risk remains privy to the firm in the second stage of the investment game described in the previous section. I consider two possibilities in relation to the observability of a firm's investment decision after the second stage and solve the three-stage (incomplete information) Bayesian game backwards like before.

4.1 Observable Investment

In this subsection, I discuss the case where firms can observe each other's investment decisions but evaluated risk remains private information.

Case (1): When **both firms invest** then each firm j for all $j = 1, 2$ knows its own actual risk $\widehat{\mu}_j$ but does not disclose it to the rival firm $-j$ for all $-j = 1, 2$ where $j \neq -j$. It is important to note that firm j does not know the rival's actual type (i.e., $\widehat{\mu}_{-j}$), though the rival firm $-j$ invests and becomes aware of its actual type. Thus, given any $\widehat{\mu}_j$ firm j's profit maximizing response depends on the rival's output for all possible type of the rival (i.e., μ_{-j}). Firm j maximizes its profit

$$\max_{q_j, \alpha_j} \frac{1}{\overline{\mu}} \int_0^{\overline{\mu}} \left[\left(a - q_j - q_{-j}\left(\mu_{-j}\right) \right) q_j - c q_j - F - \left(\widehat{\mu}_j t \left(\lambda - \alpha_j \right) q_j \right) - \frac{\left(\alpha_j q_j\right)^2}{2} \right] d\mu_{-j} \tag{14}$$

with respect to q_j and α_j where $q_{-j}\left(\mu_{-j}\right)$ is the firm $j's$ conjecture about the rival's output [10]. The equilibrium output and rate of prevention of an investing firm are

$$q_{j,II}^{ND}\left(\widehat{\mu}_j, .\right) = \frac{\left(a - c - \frac{t\lambda}{2}\left(3\widehat{\mu}_j - \frac{\overline{\mu}}{2}\right)\right)}{3} \text{ and } \alpha_{j,II}^{ND}\left(\widehat{\mu}_j, .\right) = \frac{3t\widehat{\mu}_j}{\left(a - c - \frac{t\lambda}{2}\left(3\widehat{\mu}_j - \frac{\overline{\mu}}{2}\right)\right)}$$

The *ex ante* expected profit $E\left(\pi_{j,II}^{ND}\left(\widehat{\mu}_j, .\right)\right)$ is given by

$$\frac{1}{\overline{\mu}} \int_0^{\overline{\mu}} \frac{1}{\overline{\mu}} \int_0^{\overline{\mu}} \left[\pi_{j,II}^{ND}\left(\widehat{\mu}_j, .\right)\right] d\widehat{\mu}_{-j} d\widehat{\mu}_j = \frac{(a-c)^2 - \overline{\mu} t \lambda (a-c) + \overline{\mu}^2 t^2 \left(\frac{7}{16}\lambda^2 + \frac{3}{2}\right)}{9} - F$$

Case (2): In this case, **only one firm**, say firm j, **invests** to find out the risk and keeps the information private knowledge whereas the rival firm $-j$ does not invest. Investing firm j maximizes the profit

$$\max_{q_j, \alpha_j} \left[\left(a - q_j - q_{-j} \right) q_j - c q_j - \widehat{\mu}_j t \left(\lambda - \alpha_j \right) q_j - \frac{\left(\alpha_j q_j\right)^2}{2} - F \right], \tag{15}$$

whereas the non-investing firm $-j$ does not know the actual type of firm j i.e., $\widehat{\mu}_j$. Thus, the rival's best response depends on the quantity produced by firm j for all possible types i.e., μ_j. Non-investing firm maximizes the profit

$$\max_{q_{-j}, \alpha_{-j}} \frac{1}{\overline{\mu}} \int_0^{\overline{\mu}} \left[\left(a - q_{-j} - q_j\left(\mu_j\right) \right) q_{-j} - c q_{-j} - \left(\frac{1}{\overline{\mu}} \int_0^{\overline{\mu}} \mu_{-j} d\mu_{-j} \right) t \left(\lambda - \alpha_{-j} \right) q_{-j} - \frac{\left(\alpha_{-j} q_{-j}\right)^2}{2} \right] d\mu_j \tag{16}$$

where $q_j\left(\mu_j\right)$ is what the non-investing firm anticipates firm j to produce. The equilibrium outcomes are as follows

$$\begin{aligned} q_{j,IN}^{ND}\left(\widehat{\mu}_j, .\right) &= \frac{(a-c) - t\lambda\left(\frac{3}{2}\widehat{\mu}_j - \frac{\overline{\mu}}{4}\right)}{3}, \alpha_{j,IN}^{ND}\left(\widehat{\mu}_j, .\right) = \frac{3\widehat{\mu}_j t}{\left[(a-c) - t\lambda\left(\frac{3}{2}\widehat{\mu}_j - \frac{\overline{\mu}}{4}\right)\right]} \\ \text{and } q_{-j,NI}^{ND}(.,.) &= \frac{(a-c) - t\lambda\frac{\overline{\mu}}{2}}{3}, \alpha_{-j,NI}^{ND}(.,.) = \frac{3\overline{\mu}t}{2\left[(a-c) - t\lambda\frac{\overline{\mu}}{2}\right]}. \end{aligned} \tag{17}$$

The *ex ante* expected profits of the investing and non-investing firms are given by

$$E(\pi_{j,IN}^{ND}(\widehat{\mu}_j,.)) = \frac{1}{\overline{\mu}}\int_0^{\overline{\mu}} \pi_{j,NI}^{ND}(\widehat{\mu}_j,.)\,d\widehat{\mu}_j = \frac{(a-c)^2 - \overline{\mu}t\lambda(a-c) + \overline{\mu}^2t^2\left(\frac{7}{12}\lambda^2 + \frac{3}{2}\right)}{9} - F$$

$$E\left(\pi_{-j,NI}^{ND}(.,.)\right) = \frac{1}{\overline{\mu}}\int_0^{\overline{\mu}} \pi_{-j,NI}^{ND}(.,.)\,d\widehat{\mu}_j = \frac{(a-c)^2 - \overline{\mu}t\lambda(a-c) + \overline{\mu}^2t^2\left(\frac{7\lambda^2}{16} + \frac{3}{2}\right)}{9}$$

Case (3): When **no firm invests**, then it does not matter whether there is a mandatory disclosure rule or not. Thus, the analysis is the same as in the previous section. More precisely,

$$\pi_{j,NN}^{ND}(.,.) = \frac{(a-c)^2 - \overline{\mu}t\lambda(a-c) + \overline{\mu}^2t^2\left(\frac{\lambda^2}{4} + \frac{9}{8}\right)}{9}$$

The *unilateral* and *reciprocal* incentives of a firm to invest in the research under no public disclosure are

$$UI_j^{ND} = E(\pi_{j,IN}^{ND}(\widehat{\mu}_j,.)) - \pi_{j,NN}^{ND}(.,.) = \frac{\overline{\mu}^2t^2}{24}\left(\frac{\lambda^2}{2} + 1\right) - F \quad (18)$$

$$RI_j^{ND} = E\left(\pi_{j,II}^{ND}(\widehat{\mu}_j,.)\right) - E\left(\pi_{j,NI}^{ND}(.,.)\right) = \frac{\overline{\mu}^2t^2}{24}\left(\frac{\lambda^2}{2} + 1\right) - F \quad (19)$$

The following Proposition summarizes the investment equilibrium when firms observe each other's investment decisions but the evaluated environmental risk remains private knowledge.

Proposition 2 *Under no disclosure with observable investment decision, both firms invest in research to evaluate future environmental risk if the fixed cost of investment* (F) *is at least as low as* $F^{ND} = \frac{\overline{\mu}^2t^2}{24}\left(\frac{\lambda^2}{2} + 1\right)$*; otherwise, no firm invests.*

Alternatively, I can say that both firms invest in research to evaluate future environmental risk for any liability rate

$$t \geq t^{ND} = \sqrt{\frac{24F}{\overline{\mu}^2\left(\frac{\lambda^2}{2} + 1\right)}} \text{ when } F > 0 \quad (20)$$

and for all possible liability rate if $F = 0$, when there is no disclosure rule but firms can observe each other's investment decisions. If the liability rate is sufficiently low i.e., $t < t^{ND} = \sqrt{\frac{24F}{\overline{\mu}^2\left(\frac{\lambda^2}{2}+1\right)}}$ for strictly positive fixed cost $(F > 0)$, then, in equilibrium, even without any disclosure rule, no firm invests to find out the actual risk of a future environmental damage. The above proposition can be proved by comparing eqs (18) and (19).

4.2 Unobservable Investment

Here I discuss the case where firms do not observe each other's investment decisions. I evaluate the investment equilibrium by proposing a Nash equilibrium and then derive the conditions under which no firm has an incentive to deviate from the proposed Nash equilibrium.

I propose a Nash equilibrium where both firms invest. I have to examine whether a firm has any incentive to deviate (i.e., not invest) given that the rival invests. Since the investment decision of the firms remain unobservable to each other, if a firm deviates the rival cannot observe this deviation and makes the output decision with the belief that the firm has indeed invested (and thus is aware of the actual risk), and the firm knows this, and so on so forth. In particular, the question is given that the rival $-j$ has invested and produces $q_{-j,II}^{ND}\left(\widehat{\mu}_{-j},.\right)$, whether the firm j has any incentive to deviate i.e., not invest. The deviating firm j's profit maximization problem is given by

$$\max_{q_j,\alpha_j} \frac{1}{\overline{\mu}} \int_0^{\overline{\mu}} \left[\left(a - q_j - q^{ND}_{-j,II}\left(\widehat{\mu}_{-j}, .\right)\right) q_j - cq_j - \left(\frac{1}{\overline{\mu}}\int_0^{\overline{\mu}} \mu_j d\mu_j\right) t\left(\lambda - \alpha_j\right) q_j - \frac{\left(\alpha_j q_j\right)^2}{2}\right] d\mu_{-j};$$

The profit maximizing output and abatement of the deviating firm are

$$q^U_{j,NI} = \frac{1}{3}\left(a - c - \frac{t\lambda\overline{\mu}}{4}\right), \alpha^U_{j,NI} = \frac{3\overline{\mu}t}{2\left(a - c - \frac{t\lambda\overline{\mu}}{4}\right)}.$$

The *ex ante* expected profit of the deviating firm is given by

$$\pi^U_{j,NI} = \frac{1}{9}\left(a - c - \frac{\overline{\mu}t\lambda}{4}\right)^2 + \frac{\left(\overline{\mu}t\right)^2}{8}$$

Thus, if

$$\pi^U_{j,NI} > E\left(\pi^{ND}_{j,II}\left(\widehat{\mu}_j, .\right)\right) \implies \frac{\overline{\mu}t\lambda(a-c)}{18} + F > \frac{\left(\overline{\mu}t\right)^2\left(1+\lambda^2\right)}{24} \tag{21}$$

then the investing firm deviates from the proposed investment equilibrium where both firms invest.

I now check whether a strategy profile where only one firm invests is a Nash equilibrium. If the investing firm decides to deviate given that its rival $-j$ does not invest and produces $q^{ND}_{-j,NI}(.,.)$ then the firm j maximizes

$$\max_{q_j,\alpha_j} \left[\left(a - q_j - q^{ND}_{-j,NI}(.,.)\right) q_j - cq_j - \left(\frac{1}{\overline{\mu}}\int_0^{\overline{\mu}} \mu_j d\mu_j\right) t\left(\lambda - \alpha_j\right) q_j - \frac{\left(\alpha_j q_j\right)^2}{2}\right].$$

The profit maximizing output and abatement of the deviating firm are

$$q^U_{j,NN} = \frac{\left(a - c - \frac{t\lambda\overline{\mu}}{2}\right)}{3}, \alpha^U_{j,NN} = \frac{3\overline{\mu}t}{2\left(a - c - \frac{t\lambda\overline{\mu}}{2}\right)}.$$

The *ex ante* expected profit of the deviating firm j is given by

$$\pi^U_{j,NN} = \frac{1}{9}\left(a - c - \frac{\overline{\mu}t\lambda}{2}\right)^2 + \frac{\left(\overline{\mu}t\right)^2}{8}.$$

Consequently, when

$$\pi^U_{j,NN} > E(\pi^{ND}_{j,IN}\left(\widehat{\mu}_j, .\right)) \implies F > \frac{\left(\overline{\mu}t\right)^2\left(1+\frac{\lambda^2}{2}\right)}{24} \tag{22}$$

an investing firm deviates. The following proposition summarizes the possible investment equilibria when firms cannot observe each other's investment decisions as well as do not know its rival's evaluated environmental risk.

Proposition 3 *Under no disclosure with unobservable investment decisions, both firms invest in research to evaluate future environmental risk if* $\frac{\overline{\mu}t\lambda(a-c)}{18} + F \leq \frac{(\overline{\mu}t)^2(1+\lambda^2)}{24}$, *and only one firm invests in the Nash equilibrium if* $F \leq \frac{(\overline{\mu}t)^2(1+\frac{\lambda^2}{2})}{24}$.

Note that firms' *ex ante* expected profits and strategic (unilateral as well as reciprocal) incentives to invest in risk evaluation remain the same irrespective of the observability of investment decision by firms.

Finally, observe that $UI^{MD}_j = RI^{MD}_j > UI^{ND}_j = RI^{ND}_j$ i.e., in the presence of mandatory disclosure laws firms have higher strategic incentives (unilateral as well as reciprocal) to invest in research to find out the risk of environmental damage. From Proposition (1) and Proposition (2), one can conclude the following.

Corollary 1 *In equilibrium, both firms invest in future risk evaluation only under mandatory public disclosure for any fixed cost of investment* $F^{ND} \leq F \leq F^{MD}$.

The effectiveness of mandatory disclosure laws over no disclosure in promoting strategic research in information acquisition is supported by the previous work on duopolistic firms' incentives to disclose private information[11]. In particular, duopolistic firms competing in terms of quantity find it profitable to share information about their own cost. Note that in our model the environmental risk of a firm (i.e., μ_j) features as a cost. Therefore, it does make sense that the firms (in the present duopolistic Cournot structure) have higher strategic incentive to extract information under mandatory disclosure laws i.e., when the firms will compete in terms of quantities after being fully aware of each other's type i.e., risk of causing environmental damage.

It is perhaps not surprising that a firm j's per unit preventive measure $\left(\alpha_j\right)$ is higher when the strategic incentive to invest in risk evaluation is lower under no disclosure. However, note that the net expected environmental damage $\left(\left(\frac{1}{\overline{\mu}}\int_0^{\overline{\mu}}\mu_j d\mu_j\right)\left(\lambda-\alpha_j\right)q_j\right)$ of a firm j essentially depends on the equilibrium output decision. I find that the expected equilibrium output of an investing firm under mandatory disclosure is higher than that of under no disclosure regime[12]. This, in turn, implies that the net expected environmental damage is higher under mandatory disclosure laws.

5 Conclusion

I focus on a form of incomplete information where firms are not aware of the risk of future environmental damage that can be caused by their own production process (example, oil spill, nuclear disaster, chemical plant explosion to name a few). I find that firms have strictly positive strategic incentive to invest in research to evaluate the actual risk of future environmental damage of the existing production process, irrespective of whether or not regulation requires such information about environmental risk to be disclosed. The incentive is higher under mandatory disclosure (e.g., federal security laws). In equilibrium, both firms invest when the fixed cost of investment is sufficiently low (alternatively, when the strict liability rate is moderately high). However, the net expected environmental damage of an investing firm is lower if there is no public disclosure.

Appendix

[***Ex ante*** **output under mandatory disclosure**] Recall that under mandatory disclosure as well as no disclosure regime, in equilibrium either both firms invest or no firm invests. The latter equilibrium outcomes are same under both regimes. I calculate *ex ante* expected output (when both firms invest) under mandatory disclosure

$$\frac{1}{\overline{\mu}}\int_0^{\overline{\mu}}\frac{1}{\overline{\mu}}\int_0^{\overline{\mu}} q_{j,II}^{MD}\left(\widehat{\mu}_j,\widehat{\mu}_{-j}\right)d\widehat{\mu}_j d\widehat{\mu}_{-j} = \frac{1}{\overline{\mu}}\int_0^{\overline{\mu}}\frac{1}{\overline{\mu}}\int_0^{\overline{\mu}}\frac{(a-c-t\lambda\left(2\widehat{\mu}_j-\widehat{\mu}_{-j}\right))}{3}d\widehat{\mu}_j d\widehat{\mu}_{-j} = \frac{(a-c-t\lambda\overline{\mu})}{3}$$

and when there is no disclosure

$$\begin{aligned}\frac{1}{\overline{\mu}}\int_0^{\overline{\mu}}\frac{1}{\overline{\mu}}\int_0^{\overline{\mu}} q_{j,II}^{ND}\left(\widehat{\mu}_j,.\right)d\widehat{\mu}_j d\widehat{\mu}_{-j} &= \frac{1}{\overline{\mu}}\int_0^{\overline{\mu}}\frac{1}{\overline{\mu}}\int_0^{\overline{\mu}}\frac{(a-c-\frac{t\lambda}{2}\left(3\widehat{\mu}_j-\frac{\overline{\mu}}{2}\right))}{3}d\widehat{\mu}_j d\widehat{\mu}_{-j}\\ &= \frac{(a-c-\frac{5t\lambda}{4}\overline{\mu})}{3} < \frac{(a-c-t\lambda\overline{\mu})}{3}.\end{aligned}$$

□

Notes

[1]See Antelo and Loureiro (2009) and Sengupta (2015) among others.

[2]Examples of such environmental disasters are Exxon Valdez oil spill in Alaska, BP oil spill in Gulf of Mexico, nuclear power plant disasters in Chernobyl and recently in Fukushima, etc.

[3]"No disclosure" of environmental risk can be justified under the trade secret laws; especially, in the United States, the state authorities can choose to modify the Uniform Trade Secret Acts (1979) to protect the firms from keeping their evaluated environmental risks secret.

[4]See Khanna (2000), Kim and Lyon (2011) and Kitzmueller and Shimshack (2012) among many others.

[5]See Konar and Cohen (1997), Khanna, Quimio, and Bojilova (1998), and Bui (2005) for critical analysis of effectiveness of Toxic Release Inventory on environmental performance.

[6]This is because a credible independent third party (for example, public or private research laboratory/institution, research unit of any university etc.) is responsible for the costly scientific research to evaluate environmental risk of the firm's production technology. Moreover, one can think of a credible and real threat of exposure of misreporting in the near future.

[7]Firms may differ in their respective production technologies in use but incur the same marginal cost of production.

[8]The analysis of equilibria under specific liability structures is beyond the limited scope of this paper. Nevertheless, note that in case of the *strict liability rule* (where the firms have to compensate for the exact value of the damage), the parameter t is equal to 1. If $t > 1$ then firm pays an additional penalty on top of the exact value of the environmental damage, whereas, $t < 1$ represents the *limited liability* rule.

[9]Note that, since firm $-j$ does not invest to evaluate its own environmental risk μ_{-j}, the exact value of the risk remains unknown to both the firm as well as its rival. However, equilibrium decisions and outcomes depend on this non-evaluated risk. In the rest of the paper, we use dot to depict the unknown (non-evaluated) value of a firm's environmental risk.

[10]Firm j's best response function (vis. a vis. output) is given by

$$R_j\left(q_{-j}\left(\mu_{-j}\right)\right) = \frac{1}{\overline{\mu}} \int_0^{\overline{\mu}} \frac{\mu_{-j}}{2} \left[a - c - q_{-j}\left(\mu_{-j}\right) - t\mu_j\lambda\right] d\mu_{-j}.$$

Since these firms are symmetric, we can easily find the rival's reaction function and solve for the Nash equilibrium i.e., $q_{-j}\left(\mu_{-j}\right) = q_j\left(\mu_j\right) = \frac{\left(a-c-\frac{\overline{\mu}}{2}t\lambda\right)}{3}$.

[11]See Vives (2008) for a concise survey of the relevant literature.

[12]See Appendix.

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