Available online at www.sciencedirect.com

SCIENCE DIRECT®

ACADEMIC PRESS

Journal of Environmental Economics and Management 45 (2003) 377–393

JOURNAL OF ENVIRONMENTAL ECONOMICS AND MANAGEMENT

http://www.elsevier.com/locate/jeem

A theory of environmental risk disclosure

Bernard Sinclair-Desgagné[a,b,*] and Estelle Gozlan[b,c]

[a] *CIRANO and HEC Montréal, Canada*
[b] *NSERC Industrial Chair on Site Remediation and Management, Polytechnique-Montréal, Canada*
[c] *INRA, France*

Received 26 February 2001; revised 3 September 2002

Abstract

The regulation of environmental risks increasingly emphasizes the awareness and empowerment of stakeholders. The success of this approach, however, seems to depend crucially on the quality of environmental disclosures. In this paper we investigate the amount and quality of the information that would be voluntarily delivered to some stakeholder by a potential polluter. We find that information may be hazier when the stakeholder is confident (or naive) a priori, the cost of analyzing the received reports increases little with their complexity, *or* a polluter's net expected payoff from undertaking an industrial activity that would turn out to be unsafe is small. A worried stakeholder *and* a low cost of producing more accurate figures, on the other hand, favor disclosure of high-quality information. By delivering information of very good quality, safe firms can set themselves apart more easily from dangerous ones the higher the relative ex post payoff from their current industrial activity. Implications of this framework for the scope and design of public programs of environmental disclosure are briefly examined.

JEL classification: I18; D82; C72

Keywords: Environmental reporting; Signalling; Persuasion games; Informational regulation

1. Introduction

The regulation of industrial risks to human health and the environment relies increasingly on making relevant information available to all interested parties. Examples of recent actions in this direction include government-sponsored right-to-know programs, blacklisting of notorious

*Corresponding author. Bernard Sinclair-Desgagné, CIRANO, 2020 University Street, 25th floor, Montréal, Qué, Canada H3A 2A5. Fax: (514) 985-4039.
E-mail address: bsd@cirano.qc.ca (B. Sinclair-Desgagné).

0095-0696/03/$ - see front matter
doi:10.1016/S0095-0696(02)00056-6

polluters by non-governmental organizations, the US Securities and Exchange Commission rulings that environmental liabilities and risks be publicly disclosed, and the spreading corporate practice of voluntary environmental reporting. It is widely believed that such measures constitute an effective and efficient way to have polluters internalize the potential harms they might inflict on third parties.[1] For most firms naturally seek the goodwill of neighboring communities, employees, shareholders, financial institutions, local governments and citizens in general, especially if losing that goodwill can bear significant financial consequences. Furthermore, enabling all stakeholders to actively participate in enforcing environmental regulation may also lower the administrative and political costs of enforcement.

To be successful, however, a regulation of industrial risks that is based on information disclosure calls for at least two preconditions. First, the interested parties must have the ability to act quickly and wisely on the basis of the information they receive. This means in particular that potential victims and stakeholders can access the judicial system at a reasonable cost and that the latter is effective in bringing non-compliant polluters back into compliance. Several authors have indeed emphasized the "institutional complementarity" between informational regulation on the one hand and the legal empowerment of private parties on the other (see, e.g., [27]). Second, the information provided must also be of reasonably good quality, considering the costs associated with producing, disseminating and processing data. From a public policy perspective this raises a number of positive and normative questions concerning, for instance, the accuracy of firm-specific information that would be voluntarily disclosed, the level of information provision that would be socially desirable, and the appropriate extent of mandatory standards for environmental risk disclosure. This paper seeks to address these questions.

Our theoretical study confronts a potential polluter with some major stakeholder. The former may gather and disclose more or less precise data documenting the impact of his activity on human health and the environment. The latter may approve or boycott the activity, given the a priori information she already has and the quality of the additional data she receives. This thought-experiment is cast into a simple game of incomplete information which combines features of signalling games (see, for instance, [12]) and of persuasion games (see, for instance, [19]). The figures disclosed first act as a strategic signal of whether or not the activity entails significant hazards to human health and the environment. At the same time, however, the supplied data convey substantive information concerning the activity itself : in a decision-theoretic sense they provide one further test that the stakeholder can use, if she deems it useful, to update her subjective risk assessment. This test would of course be subject to type I (suggesting to boycott an otherwise safe activity) and type II (recommending approval of a truly dangerous activity) errors. The probability of *not* making such errors, which is usually referred to as the accuracy or precision of the data, formally captures the quality of the released information.

This rather abstract model seems to fit many concrete situations. To fix ideas some illustrative cases are outlined in Table 1.

Taking stock of the accounting and economics literatures, where the analysis of disclosures is a long-standing topic, a number of alternative and perhaps richer models of disclosure could also be

[1] The main rationales for this so-called "informational regulation" are presented and discussed in [17,24,27]. There is also a young and growing literature that centers on the effectiveness of public environmental disclosures in various countries (see, e.g., [1,3,15,16], and the current survey by Tietenberg and Wheeler [27]).

Table 1
Some illustrative cases

Case 1. *Environmental permits*
In its "Reference Guide for Public Involvement in Environmental Permits [30]" the US Environmental Protection Agency identifies and describes four major milestones in the permitting processes respectively stipulated under the Clean Air Act, the Safe Drinking Water Act, the Clean Water Act, and the Resource Conservation and Recovery Act. The permitting authority first receives and reviews the permit application; a draft permit or notice of intent to refuse is next issued by the authority; the public is then given a period of at least 30 days to comment on the draft permit; and the authority finally makes a decision based on the comments received. The applicant (*here the potential polluter*) is required to provide basic information concerning the activities that may produce health and environmental hazards. Additional information can also be disclosed voluntarily, through available channels such as—in the Reference Guide's asserted increasing order of cost and informativeness—exhibits, briefings, presentations, facility tours, news conferences, observation decks, information repositories, and independent technical experts. Based on this, the authority and the public (*altogether the stakeholder*) may then use the commenting period to carefully consider or not the information provided, through community interviews, focus groups, informal meetings, workshops, public hearings, or independent technical advice. The final decision to grant or deny the permit is of course subject to some errors (*of type I or type II*) whose probability of occurrence depends necessarily on the quality of disclosures (*which are thereby analogous to a statistical test*).

Case 2. *House purchasing*
Concerns about lead-based paint hazards have brought the US Environmental Protection Agency and the US Departement of Housing and Urban Development to endow prospective tenants or buyers (*here the stakeholders*) of pre-1978 residential dwellings with the right to seek relevant information (*of unspecified precision*) from the owner (*here the potential polluter*) before renting or buying. Tietenberg and Wheeler [27] furthermore report that : "In the case of sales transactions, home buyers can also request up to ten days to conduct a lead-based paint risk assessment or inspection at their own expense prior to finalizing a sales contract." *The latter truly corresponds to a decision-theoretic test that is subject to type I and type II errors.*

Case 3. *Community awareness in Europe*
The Seveso II Directive [10] currently enforced throughout the European Community stipulates that safety reports from firms (*potential polluters*) undertaking hazardous activities be made available to the general public. Such reports should include (*more or less precise*) information concerning the major hazards, technological and organizational means of prevention and mitigation, and internal emergency plans. Member states must also insure that the public (*here the stakeholder*) is able to give its opinion (*after being given the possibility of examining the supplied data*) when new, modified or extended establishments are being considered. This is consistent with the "Section D—Community Awareness" part of the "Guiding Principles for Chemical Accident Prevention, Preparedness and Response [22]" of the Organization for Economic Cooperation and Development (OECD), which also stresses the respective costs for the firms and for the public of conveying and of processing information.

Case 4. *Environmental disclosures in corporate reports*
Various pressures from the Stock Exchange Commission (SEC) and from institutional investors (*here the stakeholders*) have caused companies (*the potential polluters*) to enhance the quantity and quality of environmental risk disclosures in their corporate annual reports. Disclosure strategies can be seen to vary widely. They include, for instance (*in increasing order of cost and accuracy*):[a]
1. disclosure of current environmental capital expenditures;
2. (1) + disclosure of current environmental operating costs;
3. (2) + accrual of an environmental liability that is included in "other liabilities" and not separately reported;
4. (2) + identification of environmental liability as a separate line item on the balance sheet.
Obviously, investors can either take such disclosures as a conclusive signal or they may submit them to independent expertise before making their final decision.

[a] The items are taken from Epstein [9]'s account of "External reporting systems." The displayed order, however, is mainly ours.

transposed to the actual setting.[2] Admittedly, our model deals neither with endogenous asymmetric information (unlike [7]), nor with costless, non-binding, non-verifiable communication or cheap talk (unlike [5]), nor with situations where the cost of disclosure is endogenous (unlike [33]), nor finally with competing information channels (unlike [6]). However, it embodies some important propositions of those literatures while explicitly portraying key elements of the above cases that we deem essential in environmental risk disclosure. One such element is the fact that voluntary reports on the hazards of complex products or processes convey strategic intentions (i.e., constitute a signal) *as well as* hard information. Another one is that industrial risk assessments must often rely on specific technical and organizational data that only the potential polluter himself can deliver. Lastly, the quality of voluntarily disclosed environmental information is largely demand-driven and dependent upon commonly known characteristics of the stakeholder, such as whether she holds a positive or a negative view of the industrial activity, whether and at what cost she can make sense of the data she receives, and whether she has the ability to pin down any misleading information.

The results derived in the upcoming sections agree with several stylized facts of environmental risk disclosure. Our model predicts, for instance, that little additional information will be voluntarily delivered to a confident stakeholder who would readily (and perhaps naively) endorse the activity; on the other hand, a worried stakeholder who openly and credibly leans towards a boycott may succeed in getting additional data from the potential polluter. This matches rather closely the recommendations in the EPA's reference guide mentioned in Table 1 (see the first case), which explicitly relate the use of independent technical experts versus briefings and informal presentations (i.e., the provision of very accurate versus coarser information) to whether public concern is respectively high or moderate. Such a finding also supports government intervention that often takes the form of mandatory disclosures, and it justifies the OECD's current insistence (Case 3 in the table) on education processes and the role of non-governmental organizations in increasing public awareness.

The present analysis furthermore refines the predictions associated with a worried stakeholder. Under some circumstances the equilibrium of the game is a pooling one in which reports associated with a safe or with a dangerous activity convey the same moderately accurate data.[3] The quality of information is then just high enough to prompt the stakeholder to make one further test based on the received data before taking action. Under opposite circumstances the equilibrium is rather a separating one in which reports surrounding a safe industrial activity are so detailed and thus expensive that they cannot possibly be imitated by a firm dealing with a noxious activity. Whether this outcome is socially preferable to the previous one will be shown to depend on the firm's cost of disclosure and the stakeholder's cost of analyzing data: under separation, only the firm engaged in the safe activity bears the cost of providing high-quality data; in the pooling case, however, *each* firm pays a relatively lower price for delivering moderately precise information but the stakeholder must bear the cost of analyzing it.

The paper is organized as follows. The following section contains a description of the basic model. Section 3 presents the main results and their interpretation. Section 4 compares these

[2] Representative earlier works in those areas include [2,8,14,29,32].

[3] All the game equilibria studied in this paper are pure-strategy equilibria and satisfy the so-called "intuitive criterion" of Cho and Kreps [4].

results with those in the existing accounting and economics literatures on disclosure. Section 5 discusses several extensions and additional policy implications of the model. Section 6 concludes.

2. The risk disclosure game

In the standard decision-theoretic framework, a decision-maker who faces uncertain prospects may choose to act right away or to postpone a decision until additional evidence has been gathered and processed. The latter usually amounts to using an imperfect test characterized by a probability β that its recommendation would match the decision-maker's best interest ($1-\beta$ is thus the probability that the test's conclusion would be misleading). This probability, which measures the precision or accuracy of the test, captures in a certain way the quality of the available data. The present model simply amends this framework by letting an opportunistic agent set β.

The outcome is the game pictured in Fig. 1. In this game a potential polluter (say a firm, $\mathscr{F}$) faces a stakeholder (say an activist organization, $\mathscr{A}$) who may approve or boycott his activity. The former knows whether this activity would eventually turn out to be harmful (i.e., *dangerous*) or not (i.e., *safe*); the latter, however, only holds prior beliefs represented by the probability $\mu < 1$ that the activity is safe.

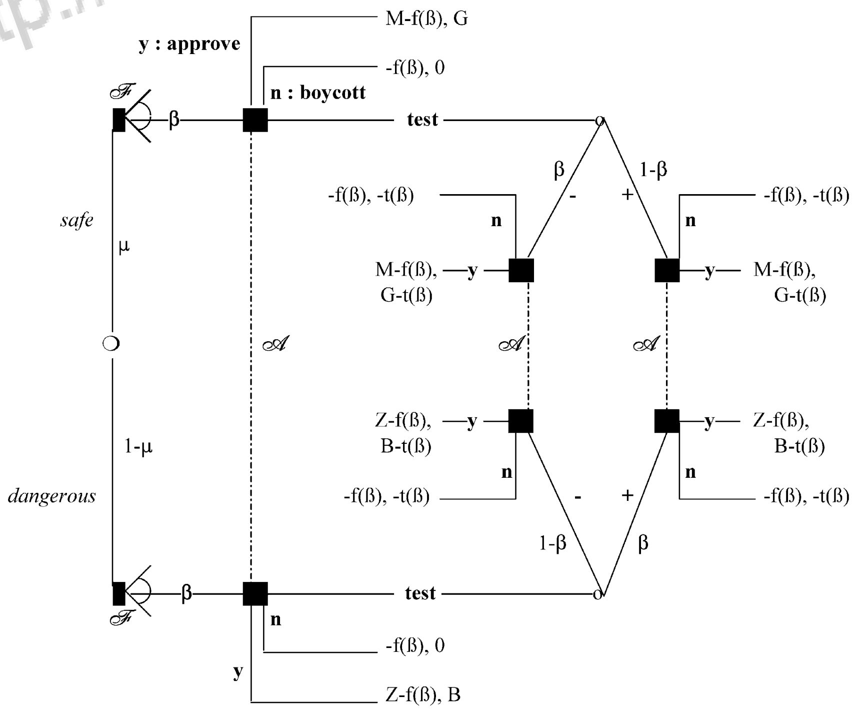

Fig. 1. The game in extensive form.

The sequence of decisions by the two players is now as follows. First, the informed firm delivers an environmental report characterized by a level of precision $\beta \in [0.5,1]$.[4] Upon receiving this report, the stakeholder directly observes β and, on this basis, she may immediately approve (y) or boycott (n) the firm's activity or she may decide instead to carefully study (test) the report before committing herself.[5] The parameter β determines whether an examination of the supplied report will yield faithful conclusions—i.e., testing "negative" ($-$) when there is indeed nothing to fear or "positive" ($+$) when the activity constitutes a real threat. After reaching a conclusion the stakeholder must finally decide to approve or to boycott the firm's activity.

The firm who produces and disseminates data of accuracy β bears a cost $f(\beta)$. An immediate boycott yields status quo incomes to the firm and the stakeholder that are both normalized at 0. Early approval, on the other hand, yields the firm positive incomes $M>0$ and $Z>0$ if the activity is respectively safe or dangerous, while the stakeholder achieves a "good" payoff $G>0$ under a safe activity but a "bad" payoff $B<0$ under a dangerous one.[6] When she rather uses the supplied report as a test and studies it thoroughly, the stakeholder incurs a cost $t(\beta)$ that varies upon the complexity of the investigated figures (which β reflects). We make the following assumptions concerning the firm's and the stakeholder's respective cost functions:[7]

- $f(\cdot)$ and $t(\cdot)$ are continuous, non-negative and strictly convex on [0.5,1].
- $f(0.5) = 0$ and $t(0.5) = 0$.
- $f(1) \geqslant \max\{M, Z\}$.

The first assumption says that the marginal cost of precision is strictly increasing. The second one means that any firm can afford the least informative reports (which are as instructive as the toss of a fair coin). The last one implies that fully accurate and complete reports are too expensive to produce and disseminate.

In this context let $\Pi(S)$ denote the set of probability distributions over S. A mixed strategy for the firm is then a function β :{safe, dangerous} $\rightarrow \Pi([0.5,1])$ mapping the actual nature of the activity into some probability distribution over disclosure quality levels. Similarly, the stakeholder's mixed strategy is made of two rules that map received messages into probability distributions over actions, that is:

K_1 : [0.5,1] $\rightarrow$ Π ({approve, boycott, test}) at the nodes where the report is received, and
K_2 : $\{-, +\}$ $\rightarrow$ Π ({approve, boycott}) at the nodes following the conclusion of a test.

[4] A probability β lower than 0.5 would mean that the stakeholder should do just the opposite of what the supplied test recommends. We assume that such misleading reports are not possible here, one possible justification being that they would entail very high penalties because the reliability of data can be verified *ex post*. The implications of relaxing this assumption have been studied, nevertheless; they can be obtained from the authors upon request.

[5] In practice a stakeholder is often able to infer the precision level of an environmental disclosure simply from the medium that is being used. As illustrated by the first case of Table 1, for instance, the US EPA publicly provides a straightforward classification of various communication channels according to their respective capacity to convey substantive information. Alternatively, as in the accounting and economics literature β may also represent the quality of an external auditor.

[6] That is: the stakeholder is hurt by pollution, but she gets some positive (direct or indirect, financial or intangible) spillover from having a safe industrial activity settle in her neighborhood.

[7] Any properly scaled, strictly decreasing and convex transformation of the entropy functions of information theory would satisfy these assumptions. The players' costs are thereby made directly proportional to the "informational content" of reports, in a precise sense.

Pure strategies are then a particular case of mixed strategies where the probability mass concentrates on one particular action. To make notation lighter, the image of a strategy function corresponding to a pure strategy will be the set of actions itself; hence, for example, $K_1(0.5)=$"boycott" will mean thereafter that the stakeholder's answer to minimal reporting by a potential polluter is to boycott the latter's activity with probability one.

The fact that the stakeholder may remain uncertain about the dangers inherent in the industrial activity is indicated by the dotted lines; the decision nodes linked together by such lines form the stakeholder's information sets. At the time she must choose what to do, the stakeholder may not be able to distinguish between two different nodes in the same information set. She always holds a subjective probability distribution over those sets, however. This distribution would of course take into account the messages received, using Bayes's rule wherever possible. After getting a report of precision β, for instance, the stakeholder believes the activity is safe with probability

$$\mu_1(\beta) = P(\text{safe}|\beta) = \mu P(\beta|\text{safe})/[\mu P(\beta|\text{safe}) + (1-\mu)P(\beta|\text{dangerous})]. \tag{1}$$

This subjective probability is updated further to

$$\mu_2(-) = P(\text{safe}|-) = \mu_1\beta/[\mu_1\beta + (1-\mu_1)(1-\beta)], \tag{2a}$$

$$\mu_2(+) = P(\text{safe}|+) = \mu_1(1-\beta)/[\mu_1(1-\beta) + (1-\mu_1)\beta)] \tag{2b}$$

when the report is analyzed and a negative (2a) or a positive (2b) conclusion is reached.

The description of the game is now complete. The following section presents and discusses the main results of the paper.

3. Main results

The propositions of this section describe some perfect Bayesian equilibria (PBE) of the risk disclosure game. Roughly speaking, a PBE is a pair of strategies $[\beta(\cdot); (K_1(\cdot), K_2(\cdot))]$ such that:[8]

(i) strategy $\beta(\cdot)$ maximizes the firm's expected payoff, given the stakeholder's strategy $(K_1(\cdot), K_2(\cdot))$;

(ii) strategy $(K_1(\cdot), K_2(\cdot))$ maximizes the stakeholder's expected payoff, given the potential polluter's strategy $\beta(\cdot)$ *and* the stakeholder's current beliefs about the harmlessness of the industrial activity;

(iii) the beliefs μ, μ_1, μ_2, are obtained successively using Bayes's rule, *whenever feasible*.

It is not possible, however, to get μ_1 through Bayes's rule when the observed precision level, say β', is inconsistent with the given equilibrium strategy, because in this case $P(\beta'|\text{safe})$ and $P(\beta'|\text{dangerous})$ must *both* (!!) be zero by definition of an equilibrium. We deal with this well-known problem by first assuming that the stakeholder will then set her beliefs via forward induction. Under the latter the stakeholder views any "surprising" (i.e., out-of-equilibrium) action by the potential polluter as truly intentional (as opposed to being the result of some mistake or

[8] See Fudenberg and Tirole [12] for a rigorous definition and complete discussion of the notion of perfect Bayesian equilibrium and its refinements.

technological failure). She thus first rules out any safety level at which a rational firm would not depart from the proposed equilibrium to deliver a report of quality β'. Once her beliefs are updated accordingly, the stakeholder's payoff-maximizing reaction must deter the delivery of β' at any other safety level.[9]

An equilibrium obtained in this manner turns out to be unique given the stakeholder's state-of-mind, which is represented by the sign of her expected utility.

Definition. The stakeholder is said to be *confident* if she holds a strictly positive expected payoff ex ante, i.e., if $\mu G + (1-\mu)B > 0$. Otherwise, the stakeholder is said to be *worried*.

The following subsections now consider the cases of a confident stakeholder and of a worried stakeholder, respectively. Each subsection will end with a brief policy discussion.

3.1. The confident stakeholder

A confident stakeholder endorses the industrial activity a priori. It is therefore a dominant strategy for the potential polluter in this case to set $\beta(\cdot) \equiv 0.5$. This readily supports our first result.

Proposition 1. *Suppose that the stakeholder is confident. Then, at the equilibrium, the potential polluter always selects an accuracy level of 0.5 and the stakeholder approves the industrial activity right away.*

Proof. It is clearly optimal for the potential polluter to set $\beta(\cdot) \equiv 0.5$ when the stakeholder approves his activity at once. On the other hand, if $\beta(\text{safe}) = \beta(\text{dangerous}) = 0.5$, then the stakeholder's beliefs (on the equilibrium path) remain constant since

$$\mu_1 = \mu P(0.5|\text{safe})/[\mu P(0.5|\text{safe}) + (1-\mu)P(0.5|\text{dangerous})] = \mu \cdot 1/[\mu \cdot 1 + (1-\mu)\cdot 1] = \mu$$

$$\text{and } \mu_2(\cdot) \equiv \mu_1 0.5/[\mu_1 0.5 + (1-\mu_1)0.5] = \mu.$$

The stakeholder's payoff from an immediate boycott is 0. And her net expected income from undertaking a test based on the current report is also

$$\begin{aligned} &P(-)\max[0, \mu_2(-)G + (1-\mu_2(-))B] + P(+)\max[0, \mu_2(+)G + (1-\mu_2(+))B] \\ &\quad = [\mu 0.5 + (1-\mu)(1-0.5)](\mu G + (1-\mu)B) + [\mu(1-0.5) + (1-\mu)0.5](\mu G + (1-\mu)B) \\ &\quad = \mu \mathrm{G} + (1-\mu)B. \end{aligned}$$

It is therefore optimal for the stakeholder to approve the industrial activity right away.[10]

[9] This amounts formally to satisfying the "intuitive criterion" of Cho and Kreps [4]. Note, incidentally, that this criterion does not uniquely identify the stakeholder's out-of-equilibrium beliefs; moreover, there exist other, more demanding, criteria which the specific (yet sensible) beliefs used in this paper might not satisfy. For a brief survey of those alternative equilibrium refinements, see [12].

[10] Discussing out-of-equilibrium beliefs and best responses seems unnecessary here.

Although the formal treatment of this case is rather straightforward, it yields interesting policy conclusions. For the potential polluter, delivering a report of precision 0.5 is the practical equivalent of not providing any useful information. Mandating some disclosure might be appropriate in this case, if one deems the stakeholder to be naive or ill-informed. As we will now see, however, a valuable alternative to this approach would also be to instill doubts in the stakeholder's mind.

3.2. The worried stakeholder

A worried stakeholder needs to be convinced before approving the industrial activity. This attitude puts pressure on the firm to produce and deliver useful data. Two mutually exclusive outcomes may now occur. A firm handling a safe activity and one dealing with real hazards may either both disclose information of the same accuracy—this is the so-called *pooling* equilibrium –or the quality of their respective report may differ—which is the so-called *separating* equilibrium. In the first case, the stakeholder who is initially skeptical will change her mind only after the conclusion of an ultimate test increases sufficiently the likelihood that the industrial activity is safe. In the second case, the worried stakeholder knows right upon observing the quality of the information delivered whether or not the current industrial activity is safe. These two outcomes clearly bear different social costs. Which one prevails, however, will be shown to depend on parameters of the model that the regulator can control.

For the time being, let us suppose that M is strictly greater than Z. This assumption could capture a situation where the dangerous firm faces significant (uninsurable) penalties ex post; it will be lifted in Section 5. This context yields an intuitive construction of the equilibrium of the game. Let us start with the following statement.

Lemma to Proposition 2. Suppose that $\beta(safe)\equiv\beta(dangerous)$ and that the stakeholder studies the report. Then, (i) *her initial beliefs remain the same upon reception of the report, i.e., $\mu_1 = \mu$; and* (ii) *the stakeholder approves the activity if and only if the report tests "negative", i.e. $K_2(-)$="approve" and $K_2(+)$="boycott".*

Proof. (i) By definition and the lemma's assumption, we have that $P(\beta|\text{safe}) = P(\beta|\text{dangerous})$. Hence, $\mu_1 = \mu$ by rule (1).

(ii) First note that the stakeholder would not study the report if her strategy were such that $K_2(-) = K_2(+) =$ "boycott" or $K_2(-) = K_2(+) =$ "approve", for her expected payoff would then be respectively $-t(\beta) \leqslant 0$ or $\mu G + (1-\mu)B - t(\beta) \leqslant 0$. By the first part, the stakeholder's expected payoff from $K_2(-) =$ "approve" is $\mu\beta G + (1-\mu)(1-\beta)B - t(\beta)$, while that from $\cancel{K_2(-)} =$ "boycott" is $\mu(1-\beta)G + (1-\mu)\beta B - t(\beta)$. Clearly, $K_2(-) =$ "approve", and similarly $K_2(+) =$ "boycott", is the better strategy (it dominates all other mixed strategy).

Fig. 2 now shows the potential polluter's revenues and costs according to the chosen precision level, the type of industrial activity and the stakeholder's decision: the horizontal straight lines correspond to immediate approval by the stakeholder, while the positively and negatively sloped

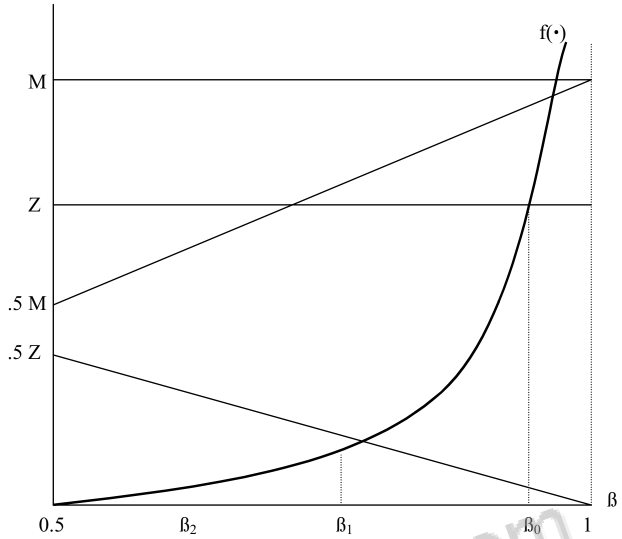

Fig. 2. The precision thresholds.

lines give the firm's expected payoff when the delivered report is studied and the firm's activity is respectively safe or dangerous.

The figure exhibits three important thresholds. The first one, named β_0, satisfies the equation $Z - f(\beta) = 0$; a firm dealing with hazardous products and processes cannot afford producing data of accuracy higher than or equal to β_0. The second one, noted β_1, maximizes the firm's expected profit $[\beta M - f(\beta)]$ if the industrial activity is safe and the stakeholder approves the industrial activity when the report tests "negative". Finally, β_2 is the smallest number in the interval [0.5,1] that satisfies the inequality

$$\mu\beta G + (1-\mu)(1-\beta)B - t(\beta) \geq 0. \tag{3}$$

When $\mu_1 = \mu$ and the latter inequality holds, the stakeholder would prefer to study the report rather than to boycott (or to approve, of course) the industrial activity right away.

Let $\beta_3 = \max\{\beta_1, \beta_2\}$. We shall suppose that the thresholds satisfy the following:[11]

- $\beta_3 < \beta_0$ and condition (3) is fulfilled for any $\beta \in [\beta_3, \beta_0]$.
- $(1-\beta_3)Z > f(\beta_3)$.

The latter assumption entails that the firm whose current activity is dangerous can afford disclosures that the stakeholder would deem to be worth studying. The former implies that the stakeholder would first choose to "test" when a reasonable amount of information is disclosed but the nature of the industrial activity remains ambiguous.

The equilibrium that finally emerges rests on whether or not we have

$$\beta_3 M - f(\beta_3) < M - f(\beta_0). \tag{4}$$

[11] Without these assumptions the current line of analysis (using similar out-of-equilibrium beliefs in the current model) would still be valid, but it would become quite tedious and policy conclusions would be weakened.

When (4) is true, it will be shown that the firm whose activity is safe chooses to signal this by providing very accurate (and expensive) information. When (4) does not hold, however, the potential polluter delivers moderately precise data that the stakeholder analyzes before taking action.

Proposition 2. (i) Separating equilibrium: *If (4) is satisfied, then the equilibrium has* $\beta(safe) = \beta_0$*,* $\beta(dangerous) = 0.5$ *and* $K_1(\beta_0)$*="approve",* $K_1(0.5)$*="boycott."*

(ii) Pooling equilibrium: *If the reverse inequality holds strictly in (4), then the equilibrium has* $\beta(safe)=\beta(dangerous)=\beta_3$ *and* $K_1(\beta_3)$*="test".*[12]

Proof. (i) Let β_4 be the unique number in [0.5,1] such that $(1-\beta_4)Z = f(\beta_4)$. And consider now the following out-of-equilibrium beliefs and moves by the stakeholder.

- For $\beta \in (\beta_0,1]$, $\mu_1(\beta)=1$ so $K_1(\beta)$ = "approve" , the rationale being that only the firm dealing with a safe activity can afford producing information of this quality.
- For $\beta \in (\beta_4,\beta_0)$, $\mu_1(\beta)=\mu$ so $K_1(\beta)$ = "test" , because the firm dealing with an unsafe activity can also deliver such data and studying the report is the stakeholder's best action in this case.
- For $\beta \in (\beta_3,\beta_4)$, $\mu_1(\beta)=0$ so $K_1(\beta)$ = "boycott" , because such a deviation, if it were followed by a test, would benefit only the unsafe firm.[13]
- For $\beta \in (0.5,\beta_2)$, $\mu_1(\beta)=\mu$ but $K_1(\beta)$ = "boycott", since the accuracy of the supplied information does not justify making a costly test in this case.

Given these beliefs and moves, and if condition (4) holds, the firm's and the stakeholder's respective actions described in the proposition clearly are best responses to one another, and the stakeholder's beliefs $\mu_1(0.5)=0$ and $\mu_1(\beta_0)=1$ are obtained via Bayes's rule.

(ii) The equilibrium lays similarly on the following out-of-equilibrium beliefs and moves by the stakeholder.

- For $\beta \in (\beta_0,1]$, $\mu_1(\beta)=1$ so $K_1(\beta)$ = "approve."
- For $\beta \in (\beta_3,\beta_0)$, $\mu_1(\beta)=\mu$ so $K_1(\beta)$ = "test" , because the firm dealing with an unsafe activity can also deliver such data and studying the report is the stakeholder's best action in this case.
- For $\beta \in (\beta_2,\beta_3)$, $\mu_1(\beta)=0$ so $K_1(\beta)$ = "boycott", because such a deviation, if it were followed by a test, would benefit only the unsafe firm.[13]
- For $\beta \in [0.5,\beta_2)$, $\mu_1(\beta)=\mu$ but $K_1(\beta)$ = "boycott", since the delivered information is then not precise enough to indicate whether the activity is safe nor to justify making a costly test.

Under the proposition's assumption, the stated actions for the firm and the stakeholder clearly are best responses to each other when the stakeholder's beliefs $\mu_1(\beta_3)=\mu$ are obtained using (1).

Fig. 2 and the arguments of the proof allow some straightforward yet interesting comparative statics. First, a lower cost of analysis $t(\beta)$ contributes to relax constraint (3), which brings β_2 (and

[12] Pooling, separation and totally mixed-strategy equilibria are all possible when (4) holds as an equality.

[13] This is where the "intuitive criterion" of Cho and Kreps [4] bites. Note, incidentally, that this criterion applies to pure strategies only.

thus β_3) down; this renders a pooling equilibrium and its lower precision level more likely. Perhaps surprisingly though, a lower delivery cost $f(\beta)$ can also have the same effect, for it leaves the right hand-side of (4) unchanged while the left-hand-side goes up because β_1 increases.[14] If the initial equilibrium is already a pooling one, however, cheaper delivery always entails that the quality of reports is upgraded at the subsequent pooling equilibrium. A decrease in the return Z from the noxious activity, on the other hand, may raise the right-hand side of (4) and thus the likelihood that the highly accurate reports associated with the separating equilibrium occur. If separation is already the outcome, however, it remains so but the quality of the information provided by the safe firm goes down. Finally, higher values of B, G, or μ contribute to relax (3), but the impact of a greater M is ambiguous since it raises (directly or indirectly through β_3) both sides of inequality (4).

From a public policy standpoint the proposition also makes it clear that, perhaps contrary to conventional wisdom, more accurate information is *not* necessarily better. To see this, notice that the *ex ante* social benefit of a separating equilibrium is given by

$$W_{\text{sep}} = \mu[G + M - f(\beta_0)], \tag{5}$$

while the one associated with a pooling equilibrium is equal to[15]

$$W_{\text{pool}} = [\mu\beta_3(G + M) + (1 - \mu)(1 - \beta_3)(B + Z)] - f(\beta_3) - t(\beta_3). \tag{6}$$

Depending on the respective sizes of the payoffs G, B, M, Z and on the behavior of the cost functions $f(\cdot)$ and $t(\cdot)$, both $W_{\text{sep}} > W_{\text{pool}}$ and $W_{\text{sep}} < W_{\text{pool}}$ are certainly possible. The higher accuracy brought by a separating equilibrium is therefore not always socially desirable.

Other policy implications are discussed in Section 5. Beforehand, the following section will briefly position the above results within the literatures on disclosure and games of persuasion.

4. Relationships with the existing literature

The presence of the cost functions $f(\cdot)$ and $t(\cdot)$ clearly matters for the previous analysis. Without these, or equivalently if $f(\cdot) \equiv 0$ and $t(\cdot) \equiv 0$, our model would give way to the well-known "disclosure principle" of persuasion games ([13,19,20,21]): if the stakeholder needs to be convinced, precision is costless, and the potential polluter cannot lie, then there is an equilibrium where the latter provides fully accurate information and reveals the true nature of his activity. This equilibrium would be supported by the so-called "sophisticated-skepticism" argument that, in such a context, the stakeholder completely discounts any partial reporting because she believes that the firm dealing with a safe activity has no reason to conceal this.

Through Propositions 1 and 2, however, our model encompasses another "classical" result due to Verecchia [32]: positive costs of reporting imply that vague disclosures do not necessarily signal

[14] Of course, the assumptions that were made about delivery costs in Section 2 must remain true, so in particular all considered function $f(\beta)$ are strictly convex.

[15] The cost of making a type I error (boycotting a safe activity) does not appear in this formulation.

a bad state of nature, for the specific payoff and cost structure can encourage a safe firm to reveal as little information as would a dangerous firm.

Reporting costs can easily be linked to the preparation and dissemination of data or to the proprietary nature of information. More specifically, the additional feature that the cost of reports increases with their accuracy makes it reasonable to interpret the precision levels β as measurements of an auditor's quality (or of the reliability of any outsider who assesses the environmental impact of the current industrial activity). Concerning the choice of auditor by an opportunistic firm, Titman and Trueman [28] have argued earlier that the more benign the industrial activity the higher the quality of the auditor, while Hughes [14] showed that a firm's handling of a safe activity may not necessarily induce higher auditor quality if there are other means (e.g., ownership in the project) by which the firm could signal her goodwill. The above analysis brings these opposite conclusions together: according to Proposition 2, cost and payoff functions that satisfy condition (4) induce a monotone relationship between harmlessness and audit quality, but functions inconsistent with that condition make the safe as well as the dangerous firm agree on their choice of auditor.

Our model does not address explicitly the timing of disclosures (unlike, for example, the models of Dye [8], Truman [29], and Teoh and Hwang [26]). As suggested by Verrecchia [32], however, one may assume that the cost of disclosure decreases with time. Proposition 2 and its comparative statics implications would now predict that reporting strategies which form a pooling equilibrium become more attractive but tend to deliver more precise data as time elapses. Once a pooling equilibrium is at sight, there is therefore an incentive for the regulator to postpone public hearings. But if it is the separating equilibrium that first shows up and turns out to be socially better, then the regulator will rather set a deadline at the last time t^* where $W_{\text{pool}} \leqslant W_{\text{sep}}$.

In a paper closely related to ours, Fishman and Hagerty [11] investigate the circumstances where it is desirable to limit further a potential polluter's discretion on disclosures. Our model is of course analogous to theirs but it takes precision as a continuous variable and, more importantly, brings in several traits of the stakeholder. This often yields complementary insights: for example, that a confident stakeholder renders voluntary disclosure unattractive, even to a firm handling a safe activity; and that if more precision is always desirable in the presence of a worried stakeholder, then less discretion might be granted to those potential polluters whose *lower* cost of data production tends to produce a pooling equilibrium.

Finally, a number of models have recently dealt with the cost of analyzing or acting upon the reports received. Shin [23], for instance, assumes the stakeholder is uncertain about the exact information possessed by the potential polluter. This feature seems rather close to the pooling equilibrium described in Proposition 2, where the stakeholder is unable to update her beliefs on the basis of the received report and is also uncertain about the validity of the conclusions a study of that report will yield. Some costs of decision making are also brought up by Lewis and Poitevin [18], who deal with type I and type II errors, and by Stocken [25], who allows specific retaliatory punishments in a repeated-game setting. Via the function $t(\cdot)$ this paper rather emphasizes the cost of counter-expertise. This seems to make sense if one wants to examine informational regulation vis-à-vis environmental risks, for the empowerment of stakeholders that is thereby pursued hinges to a large extent on the affordability of independent experts.

5. Further extensions and policy issues

Let us now examine what happens if we change some of the assumptions made in Subsection 3.2. Suppose, first, that holding a dangerous industrial activity entails greater revenues, so $M < Z$. Then the only possible equilibrium under this payoff structure would be a pooling one, since a safe firm cannot credibly signal its goodwill. In this case a regulator who favors s eparation between safe and harmful activities might want to enforce substantial ex post penalties on the dangerous firm; by the above analysis the fine t would then have to be set so that $M > Z - t$.

Now, let $(1 - \beta_3)Z < f(\beta_3)$, which means that a firm whose current activity is dangerous cannot afford disclosures the stakeholder would consider a valuable test. According to Fig. 2 and the argument supporting Proposition 2, an outcome corresponding to a pooling equilibrium would then be impossible. A possible remedy to this might be to decrease the data production cost $f(\beta)$ enough, via direct subsidies to disclosure, better information technology, or the improvement of internal auditing.

Returning to the context of Section 3.2, where the stakeholder is worried and $M > Z$, let us now examine some policy issues relating to the opportunity of mandatory standards and to the use of taxes and subsidies.

5.1. Mandatory standards for environmental disclosure

In this paper mandatory standards can be defined as the imposition of a floor level $\underline{\beta} > 0.5$ on the precision of reports. Let $\beta_5 = \max\{\beta_3, \underline{\beta}\}$ denote the precision level that is now associated with a pooling equilibrium. If $W_{\text{sep}} > W_{\text{pool}}$ but pooling is the occurring outcome, then a benevolent regulator would clearly want to reset $\underline{\beta}$ sufficiently higher than β_3, perhaps up to the point at which $(1 - \beta_5)Z < f(\beta_5)$, so that a safe firm has no better choice than to signal the nature of its activity. The reverse is true in the opposite case where $W_{\text{sep}} < W_{\text{pool}}$ but the separating outcome prevails; however, putting lower standards β may not suffice to induce pooling and the regulator may need to use other instruments as well.

5.2. Taxes and subsidies

Another way to implement a desired disclosure level is to affect the cost functions directly through taxes and subsidies.

Consider first the possibility of adding an amount T to the stakeholder's cost of analysis $t(\cdot)$, a positive T being interpreted as a tax and a negative T as a subsidy. According to Fig. 2 and the second proposition, such a subsidy would increase the likelihood of a pooling equilibrium while a tax would do just the opposite. Therefore, if the more precise data of a signalling equilibrium is always socially desirable, then the regulator should *tax* independent analyses by the stakeholder.

Considering finally the impact of changing the data production cost $f(\cdot)$ by adding a fixed amount F to it, a subsidy $F < 0$ would increase, and a tax $F > 0$ decrease, the precision levels associated with a separating outcome. If the regulator wants to depart from a separating equilibrium, therefore, a *subsidy* to environmental reporting would be the right instrument to use.

6. Concluding remarks

There are circumstances under which an informed potential polluter cannot credibly document and disclose all his information to every external stakeholder. This paper examined the factors that might influence the quality of voluntary disclosures in this case. We modelled quality as the precision (in the usual sense of decision analysis) of a test that would be based on the delivered data. Then we brought up specific features of the stakeholder, such as her mood (confident or worried) and her cost of analyzing environmental reports, along with more customary items like the cost of producing and delivering information. Our main results predict, first, that voluntary disclosures would be very vague and inexpensive when the stakeholder is a priori confident about safety (Proposition 1); second, that the necessity to reassure a worried stakeholder could force a firm to invest in more accurate environmental reporting (Proposition 2); and third, that very precise reports would lead a stakeholder to approve the proposed industrial activity right away while moderately precise data would be more closely examined (at an incremental cost) by a worried stakeholder before she decides to endorse or oppose the corresponding activity (Proposition 2). These predictions, in particular those relating the quality of disclosures to the stakeholder's level of concern, seem to be verified in various concrete settings, such as the ones sketched in Table 1.

Under combined pressure from public regulators, firms, and stakeholders in general, environmental reporting is currently undergoing substantial changes. The main goal of this paper was to provide some formal guidance for this process; much more can and should certainly be done. An example of what is already at hand, however, would be the following. The "One-Stop Environmental Reporting Program" [31] began in 1995 as a Presidential Initiative to upgrade environmental data management and disclosure. An important stated goal is to reduce reporting burden on industries and communities. The present analysis reveals that direct subsidies to environmental reporting would actually be an imperfect substitute for mandatory disclosure standards, because unlike the latter they might allow a dangerous firm to match the quality of the information expected from a safe firm.

Acknowledgments

We are grateful to Bruno Biais, Peter Bogetoft, Linda Bui, Nathalie Dierkens, Steve Hansen, Steven Huddart, Murgie Krishnan, Stéphan Marette, Eric Noreen, Eric Rasmusen, Ariel Rubinstein, Réjean Samson, Kathy Segerson, Domenico Siniscalco, Tom Tietenberg, and Bob Winkler for valuable discussions on the topic of this paper. We also wish to thank seminar participants at INSEAD, HEC-Paris, Stanford University, and the University of Connecticut for their comments on earlier drafts. The editor, Charles Mason, and two anonymous referees greatly helped to improve the presentation. Bernard Sinclair-Desgagné thanks the Department of Economics at Boston University for its hospitality while this paper was being written. Estelle Gozlan gratefully acknowledges financial support from the NSERC Industrial Chair on Site Remediation and Management at École Polytechnique de Montréal.

References

[1] S. Afsah, B. Laplante, D. Wheeler, Controlling industrial pollution: a new paradigm, Policy Research Department, World Bank, Working Paper no. 1672, 1996.
[2] R. Bowden, Statistical Games and Human Affairs, Cambridge University Press, Cambridge,UK, 1989.
[3] L. Bui, C. Mayer, Regulation and capitalization of environmental amenities: evidence from the toxics release inventory in Massachusetts, Boston University, 2000, unpublished manuscript.
[4] I.K. Cho, D. Kreps, Signalling games and stable equilibria, Quart. J. Econom. 102 (1987) 179–221.
[5] V. Crawford, J. Sobel, Strategic information transmission, Econometrica 50 (1982) 1431–1451.
[6] D. Diamond, Optimal release of information by firms, J. Finance 40 (1985) 1071–1094.
[7] X. De Groote, Information Disclosure and Technology Choice, INSEAD WP, Fontainebleau, France, 1992.
[8] R. Dye, Disclosure of non-proprietary information, J. Accounting Res. 23 (1985) 123–145.
[9] M.J. Epstein, Measuring Corporate Environmental Performance. Best Practices for Costing and Managing an Effective Environmental Strategy, Irwin, Chicago, 1996.
[10] European Commission, Seveso II Directive, Document no. 96/082/EEC, 1996.
[11] M.J. Fishman, K.M. Hagerty, The optimal amount of discretion to allow in disclosure, Quart. J. Econom. 105 (1990) 427–444.
[12] D. Fudenberg, J. Tirole, Game Theory, MIT Press, Cambridge, MA, 1991.
[13] S. Grossman, The informational role of Walrasian and private disclosure about the product quality, J. Law Econom. 24 (1981) 461–483.
[14] P. Hughes, Signaling by direct disclosure under asymmetric information, J. Accounting Econom. 8 (1986) 119–142.
[15] M. Khanna, W.R. Quimio, D. Bojilova, Toxic release inventory: a policy tool for environmental protection, J. Environ. Econom. Manage. 36 (1998) 243–266.
[16] M. Khanna, W.R. Quimio, D. Bojilova, Information as regulation: the effect of community right-to-know laws on toxic emissions, J. Environ. Econom. Manage. 35 (1997) 109–124.
[17] P.R. Kleindorfer, E.W. Orts, Informational regulation of environmental risks, Risk Anal. 18 (1998) 155–170.
[18] T. Lewis, M. Poitevin, Disclosure of information in regulatory proceedings, J. Law, Econom. and Organization 13 (1997) 50–73.
[19] P. Milgrom, Good news and bad news: representation theorems and applications, Bell J. Econom. 12 (1981) 380–391.
[20] P. Milgrom, J. Roberts, Relying on the information of interested parties, Rand J. Econom. 17 (1986) 18–32.
[21] M. Okuno-Fujiwara, A. Postlewaite, K. Suzumura, Strategic information revelation, Rev. Econom. Stud. 57 (1990) 25–47.
[22] Organization for Economic Cooperation and Development (OECD), Guiding principles for Chemical Accident Prevention, Preparedness and Response, OECD/GD (92) 32, 1992.
[23] H. Shin, News management and the value of firms, Rand. J. Econom. 25 (1994) 58–71.
[24] B. Sinclair-Desgagné, Environmental risk management and the business firm, In: T. Tietenberg, H. Folmer, (Eds.), The International Yearbook of Environmental and Resource Economics 2001/2002, Edward Elgar, Northampton, MA, October 2001.
[25] P. Stocken, Credibility of voluntary disclosures, Rand. J. Econom. 31 (2000) 359–374.
[26] S. Teoh, C. Hwang, Nondisclosure and adverse disclosure as signals of firm value, Rev. Financial Stud. 4 (1991) 283–313.
[27] T. Tietenberg, D. Wheeler, Empowering the community Information strategies for pollution control, In: H. Folmer, H.L. Gabel, S. Gerking, A. Rose (Eds.), Frontiers of Environmental Economics, Edward Elgar, Northampton, MA, 2001.
[28] S. Titman, B. Trueman, Information quality and the valuation of new issues, J. Accounting Econom. 8 (1986) 159–172.
[29] B. Trueman, Why do managers voluntarily release earnings forecasts?, J. Accounting Econom. 8 (1986) 53–71.

[30] US Environmental Protection Agency, Public involvement in environmental permits. A reference guide, EPA document No. 500-R-00-007, August 2000.
[31] US Environmental Protection Agency, One-stop reporting. Reinventing Environmental Information Program, November 2000.
[32] R.E. Verrecchia, Discretionary disclosure, J. Accounting Econom. 5 (1983) 179–194.
[33] A. Wagenhofer, Voluntary disclosure with a strategic opponent, J. Accounting Econom. 12 (1990) 341–363.