Natural disasters and information disclosure

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Abstract: ***This paper investigates the role of information in a context characterized by uncertainty about the occurrence of environmental disasters. We model a two-stage game where in the first stage an environmental authority chooses whether to acquire (freely) and disclose (costly) information to an agent potentially affected by the negative effects of a natural disaster, while in the second stage, given the choice to spread or not the information, and given the usefulness of such information, the agent decides her level of costly effort to be devoted to reducing the likelihood of the disaster. As the information can be "good news" or "bad news", counterintuitive impacts on the chosen effort and on the incentives to spread the information by the environmental authority may arise. More specifically, when the information is very likely to be good news, the effort decreases with information availability and this may lead the environmental authority to choose not to spread the relevant information, depending on the degree of uncertainty, on the impact of the disaster, on the costs of effort and on the costs the authority has to bear to spread information.***

***Keywords*:** public information, uncertainty, environmental disasters.

Introduction

Ozone layer depletion and climate change are maybe the most well known and debated examples of global environmental problems. Climate change has led to dramatic changes in temperatures, which are suggested to be among the causes of extreme weather events, like hurricanes, tsunamis, floods, ice melting etc. In a NOAA[1] report (2016), the concept of natural disaster is explained dividing "weather hazards" and "environmental hazards"[2]; both are referred to tornados, floods, hurricanes, tsunamis, wildfires, volcanoes, but in the second case the occurrence of these conditions is due to the climate change instead of mere meteorological factors. In this sense, the role that individuals play in this framework

[1] NOAA is the acronym for National Oceanic and Atmospheric Administration.

[2] A natural *hazard* is a natural phenomenon that might have a negative effect on humans or the environment. The risk derived from a natural hazard is obtained multiplying the hazard times the probability of its occurrence.

is crucial; most of the environmental damages are referred to as “man-made disasters”, especially those related to production and industrial development.
The relevance of environmental disasters is also increasing at a local level. A recent example is the case of the the Genoa (Italy) flood of 9 and 10 October 2014, occurred as a result of heavy rainfall, which caused approximately 395 mm by the overflow of the torrents Bisagno, Sturla, Fereggiano, Noce, and Torbella, but also of urbanization and soil sealing.
The quantitative evidence on catastrophes and the related economic, social and environmental damages confirms the relevance of this issue worldwide. *Munich Re* (2016*)* categorized as natural disaster about 750 events, stating that more than half was recorder in Asia; the 27% of the overall economic losses related to those events came from the earthquake in Japan, about 30-31% of the losses came from meteorological episodes[3]. In Europe, the overall losses from natural catastrophes during the end of 2016 were about € 4.4 billion of which € 1.7 billion of insured losses[4].

These considerations call for further investigations of factors driving environmental catastrophes and damages. This paper focuses on two interlinked aspects, namely the effort in reducing the likelihood of a disaster to take place and the impact of information provision by public authorities.

Information plays a crucial role, in driving people’s effort to reduce the likelihood and/or the consequences of an environmental disasters. The *Adaptation and Resilience Action Plans* (2011) states that the role of public authorities is fundamental to face this kind of issues. The “European Civil Protection Mechanism[5] suggests, in particular, the importance of *information disclosure*. According to Leiserowitz (2007), interests in the risks arising from natural disasters can be aroused by drawing attention to the potential personal damages, but not everyone has the same perception of danger or risk that threatens a common resource. The management of natural disasters and emergencies requires a great communication system in terms of warnings, sharing of information and disasters probability patterns (Reynolds and Seeger *et al*., 2005). Risk and vulnerability can sometimes be reduced if there is an adequate means of predicting a hazardous event.

[3] See munichre.com
[4] The South is the most vulnerable region in Europe, followed by the West and the North-West. The risk of flood is higher along coasts but the drier and hotter South is more prone to fires and earthquakes (EPSON climate 2011).
[5] Further information visiting http://ec.europa.eu/echo/what/civil- protection/mechanism_en.

Basing on a high probability that a hazardous event will occur, the issue *early warning*[6] would be effective if the communication and public information systems are effective and likely to have an impact, due to the source of information being credible (McGuire, 1969; Zimbardo and Ebbesen, 1970). It is not easy to manage disasters information and disclose them to population (Sorensen, 2000). Information recipients will be probably unfamiliar with forecasts and this may detract from the usefulness of public hearings and other settings where exchange might take place between the providers of information and concerned citizens (National research Council, 1989).

Given available information, another crucial variable affecting the likelihood and impact of an environmental disaster is the *effort* that potentially affected agents may exert to reduce negative effects of their actions (e.g. not set on fire in fire-prone areas, build barriers to avoid flooding, etc.). The level of effort an individual decides varies according to the information available. On the other hand, even when information is costless for public authorities, its diffusion in a credible way implies costly activities by such authorities. We consider this trade off by investigating the role of (costly) information diffusion on the effort chosen by individuals potentially affected by a natural disaster, to assess the (potentially perverse) incentives for a supervisory authority to spread information.

We link to several strands of literature. Starting from Stigler (1961), we are accustomed to considering information as a source of knowledge and therefore a kind of power. In a framework characterized by uncertainty, the degree of available information concerning the damage from a risk event, is essential or, in any case, influent on individual effort choices. Regarding the potential harmful of knowledge, Bostrom (2011) reports the idea that some information could harm markets; among others there are two type of potential harmful information: the "unveiling hazard" information which states that the efficiency of some markets depends on the existence of a shared ignorance, and the "recognition hazard" under which some social framework could be affected from public release of information. The provision of public information is generally based on complex data collection procedures, performed by authorities and statistics; on the contrary, private

[6] An early warning is a statement that a high probability of a hazardous event will occur, based on a prediction or forecast. If a warning is issued, it should be taken as a statement that "normal routines of life should be altered to deal with the danger imposed by the imminent event".

agents select the information according to their needs, so they can respond quickly to changes in the quality of information available. The efficient use of information reflects the social value of choices.

Some authors consider different levels of information, when individuals are risk-neutral and there is uncertainty regarding the total cost of emissions with a total information, the effort in emission reduction is always verified (Finus *et al.*, 2014). The payoff for individuals with strategic interactions is always increased if they have information, hence, the net effect of the news is positive (Ulph, 1996[7]); according to some scholars, the effect of information is positive (or null) on individuals efforts (Dellink and Finus, 2012). On the contrary, Kaplow and Shavell (1996) show that agents may find in their interest to ignore available information, e.g. on the expected loss entity. Also, several papers suggest that public information disclosure can reduce social welfare (Morris and Shin, 2002; Hellwig, 2005; Roca, 2010; Conrad and Heihemann, 2008). Studying the optimal disclosure policy of a regulator, Goldstein and Leitner (2015) focus on the trade-off between information release and risk-sharing opportunities, finding that it is optimal for a regulator not to disclose information in good times and partially disclose during bad times. On the contrary, social welfare is increased if there is a greater degree of transparency of information among agents (Angeletos and Pavan, 2004).

Another strand of literature we link to deals with effort choices by potentially affected individuals in the presence of uncertainty. If the uncertainty concerns the type of damage that an individual may suffer, choices will be dictated by its attitude towards risk (Sandler and Posnett, 1987; Julienne and Salanié, 1999; Levy and Markowitz, 1979; Boucher and Bramoullé, 2010). Uncertainty can have a net positive impact on risk-averse polluters: if pollution reduction generates benefits in terms of uncertainty reduction, then individuals may be better-off and incentives to pollute may be lowered (Bramoullé and Treich, 2009). Instead, Quaas and Baumgartner (2006) show that in an ecosystem characterized by uncertainty, risk-averse individuals may acquire insurance to mitigate risks, lowering environment quality.

We link to these two strands of the literature by showing that, even in a context characterized by risk neutrality, perverse impacts on the effort in reducing the likelihood of an environmental disaster may arise, due to information spreading. This may reduce the incentives of a benevolent environmental authority to spread available information.

[7] The model shows that if players are not willing to pay to obtain additional information they become worse-off.

The rest of the paper is organized as follows: *section 2* introduces the two-stage theoretical model. *Section 3* solves our simple game backwards and interpret the main results *Section 4* discusses and concludes.

The game.

We model a two-stage game solved backwards, featuring a benevolent environmental authority, in charge of disclosing potentially relevant information to economic agent(s) potentially affected by an environmental disaster, and economic agents themselves, choosing the amount of (costly) effort to be devoted to reducing the likelihood that the environmental disaster takes place.

The structure of the game is as follows:

1. In the first stage the environmental authority chooses whether to acquire relevant information concerning the consequences of a natural disaster and to bear a fixed cost to make it public available to a potentially affected agent. Such information is available to the authority for free, but its diffusion to the potentially affected agent requires a fixed cost F. The choice by the environmental authority has the aim of maximizing social welfare, accounting for the agent's expected welfare as well as for the social impact of the environmental disaster, anticipating the impact of information disclosure on the agent's choices.
2. In the second stage, and taking provided information as given, a (risk neutral) agent chooses the effort to reduce the likelihood of the natural disaster to take place; we label this effort as a. To simplify matters, we assume that in the absence of effort the environmental disaster takes place with certainty. As a result, the probability that the disaster takes place is given by $1 - a$. If no information is provided, or if information is useless (see below), then the agent takes the value of private loss from the natural disaster as given and equal to L. If the disaster takes place, it also generates a social cost equal to L_S which is not accounted for by the agent. It is therefore an externality.

As anticipated, the information implies a fixed cost F; we assume that information is useful with probability $1 - u$ and useless with probability u; when information is useful, it can provide *good news* or *bad news* ex-post. More specifically, when information is useful, it provides good (bad) news with probability v e $(1 - v)$; implying that the ex post loss from the disaster born by the agent, if it takes place, is $(1 - x)L$ $((1 + x)L)$. In words, good (bad) news imply that the *ex post* loss is lower (larger) than anticipated by a factor $x \in (0,1)$. To highlight the impact on the choice of the regulated agent of information provision we assume that the social loss from the natural disaster is, instead, unaffected by information provision.

Second stage. Agent choosing effort.

In the second stage, the agent chooses the effort to reduce the probability of an environmental disaster, taking as given the (expected) value of the related loss. The latter depends on whether the environmental authority has chosen to spread the available information or not, as well as on the information being useful or not. Clearly, if no information is provided and if the provided information is useless, then the agent keep the *a priori* belief that the loss value is L. If, on the other hand, the environmental authority provides useful information, then the agent updates the *ex-ante* expected value of the loss to $\big(v\,(1 - x) + (1 - v)(1 + x)\big)L$.

Useless or no information.

When the information is useless or is not made available by the environmental authority in the first stage, then the agent accounts for a value of the loss given by L. This must be weighted by the probability of disaster $1 - a$, which as already explained, decreases with the effort exerted by the agent. The choice of the effort affects therefore the expected value of the loss under the agent's perspective.

The agent chooses the effort to minimize expected costs, which, in our simple setting, reduce to:

$$\min_a \frac{ca^2}{2} + (1 - a)L,$$

Where $\frac{ca^2}{2}$ are increasing and convex effort costs and c is a strictly positive cost parameter. First order necessary and sufficient conditions require:

$$ca - L = 0$$

As a results the equilibrium effort is (where we label with the subscript n the case of no or useless information)[8]:

$$a_n = \frac{L}{c} \tag{1}$$

Straightforward comparative statics imply $\frac{da_n}{dc} < 0$ and $\frac{da_n}{dL} > 0$. When the information is useless (or when agents are not informed) the level of effort increases with the expected loss (L) and decreases with the cost parameter, as it is reasonable.

Useful information

Under our assumptions concerning the potential good (v)or bad news $(1 - v)$ when information is useful, we can conclude that, when useful information is provided, the agent beliefs concerning the expected value of the loss from the environmental disaster is given by $\big(v\,(1 - x) + (1 - v)(1 + x)\big)(1 - a)L$.

The agent chooses therefore the effort to minimize the following expected costs:

$$\frac{ca^2}{2} + \big(v(1 - x) + (1 - v)(1 + x)\big)(1 - a)L$$

First order (also in this case necessary and sufficient) conditions require:

[8] We assume $0 < L < c$ to have $a_n \in (0,1)$.

$$ca - \big(v(1-x) + (1-v)(1+x)\big)L = 0$$

The level of effort of informed agents which are risk-neutral is therefore[9]:

$$a_i = \frac{L}{c}\big(v(1-x) + (1-v)(1+x)\big) \tag{2}$$

Comparative statics are qualitatively similar to the ones with respect to L and c in the absence of information, i.e. $\frac{da_i}{dc} < 0$ and $\frac{da_i}{dL} > 0$. On the other hand, $\frac{da_i}{dv} = \frac{-2xL}{c} < 0$. Hence, the higher is the probability of an ex-post good news, the lower is the effort of informed agents. This conclusion already suggests a potentially counterintuitive avenue driving the incentives of the environmental authority to choose to spread the information in the first stage. Also, $\frac{da_i}{dx} = \frac{L}{c}(1-2v)$. As a result, $\frac{da_i}{dx} \geq 0$ if $v \leq \frac{1}{2}$. The wider the difference (in terms of expected loss value) between the good and the bad state of the world ex-post, the larger (smaller) is the effort when the probability of good news is sufficiently low (high). Indeed, when the probability of good news is relatively small, a larger x implies that the likely bad news is more severe, driving effort up. The opposite happens when v is sufficiently large.

Comparing effort level in the absence and in the presence of (useful) information, from (1) and (2) we get:

$$a_i - a_n = \frac{L}{c}x(1-2v).$$

As a result, effort can be lower or higher if no information is acquired, depending on the probability of good news (v). Notice that, $a_i = a_n = \frac{L}{c}$ if $v = \frac{1}{2}$. When it is more likely that the information is good news ex post, i.e. $v > \frac{1}{2}$, then $a_i < a_n$, as in this case the good news drives effort down if information is provided and useful. The opposite happens when $v < \frac{1}{2}$. This leads us to our first Proposition.

[9] $0 < L < c$ also guarantees $a_i > 0$. $a_i < 1$ requires $L\big(v(1-x) + (1-v)(1+x)\big) < c$. As $\big(v(1-x) + (1-v)(1+x)\big) < 1$ if $v > \frac{1}{2}$, then $0 < L < c$ guarantees $a_i \in (0,1)$ when $v > \frac{1}{2}$, while otherwise we have to assume $L\big(v(1-x) + (1-v)(1+x)\big) < c$.

Proposition 1. *Useful information provision may decrease equilibrium effort level. This happens when the probability that the loss is ex-post lower than expected is sufficiently large.*

Proposition 1 implies that the decision by the environmental authority to spread the information may also affect negatively the likelihood that the disaster takes place. We can therefore anticipate that the authority could trade off this impact with the related costs and social welfare.

First stage: information acquisition and diffusion

Assume now that, anticipating the impact of the information choice on effort levels, an environmental authority chooses whether to buy and distribute information (paying a fixed cost F).

Recall that the information is available for free to the authority, and that the environmental disaster would generate a social loss equal to L_s which adds to the private loss borne (and accounted for) by the agent in the second stage.

Define the expected social costs arising in the case of no (or useless) information as follows:

$$C_n = \frac{c{a_n}^2}{2} + \big(v(1-x) + (1-v)(1+x)\big)(1-a_n)L + (1-a_n)L_s \tag{3}$$

while if information is useful, minimum costs are:

$$C_i = \frac{c{a_i}^2}{2} + \big(v(1-x) + (1-v)(1+x)\big)(1-a_i)L + (1-a_i)L_s \tag{4}$$

Of course, in order to have that a_i is chosen by the agent, the benevolent environmental authority must bear fixed cost of information diffusion F, and information must turn out to be useful, which, as already outlined, happens with probability *$(1 - u)$*.

Information is therefore distributed if social expected costs savings are larger (in absolute terms) than fixed costs. As a result, expected costs are $uC_n + (1-u)C_i + F$ if information is acquired, and C_n if information is not acquired. Thus, the authority will acquire and distribute information if $uC_n + (1-u)C_i + F < C_n$; or

$$F < F_i = (1-u)(C_n - C_i) \tag{5}$$

Where, from (3) and (4),

$$C_n - C_i = \frac{c}{2}(a_n^2 - a_i^2) + \left[L\big(v(1-x) + (1-v)(1+x)\big) + L_s\right]\big((1-a_n)(1-a_i)\big)$$

And where we label F_i as the relevant fixed cost threshold. Substituting from (1), (2), (3) and (4) into (5),

we get[10]:

$$F_i = \left(\frac{1-u}{2}\right)\left(\frac{Lx(1-2v)}{c}\right)\big(2L_s + Lx(1-2v)\big) \quad (6)$$

To show how the incentive to spread information changes with relevant parameters, we can see how the fixed cost threshold changes with those parameters. More specifically, parameters that increase F_i imply larger incentives to information diffusion, while parameters that decrease F_i imply a lower likelihood that the benevolent authority indeed chooses to provide the agent with information.

Focusing first on the social loss related to the environmental disaster, it is self evident from (6) that information provision incentives are smaller the larger is L_s when $v > \frac{1}{2}$, i.e. when the likelihood that information conveys good news ex post is sufficiently large. This is reasonable: the larger the social loss, the more valuable is the agent's effort. In this respect, information is bad for expected social costs when it decreases equilibrium effort by the agent, and this is indeed the case when $v > \frac{1}{2}$. The opposite happens when the probability of good news is sufficiently small (i.e. $< \frac{1}{2}$).

Turning to the impact of the cost parameter *c*:

$$\frac{dF_i}{dc} = \frac{1}{2}\frac{Lx}{c^2}(1-2v)(u-1)\big(2L_s + Lx(1-2v)\big)$$

[10] Notice that F_i>0 always holds when $v < \frac{1}{2}$, while it requires $L_s < \frac{Lx}{2}(2v-1)$ when $v > \frac{1}{2}$.

so that $v < \frac{1}{2}$ is sufficient for $\frac{dF_i}{dc} < 0$, while if $v > \frac{1}{2}$ then $\frac{dF_i}{dc} < 0$ is a consequence of $\left(2L_s + Lx(1-2v)\right) < 0$, which is needed to have a strictly positive F_i (see footnote 21). In words, both when the effort increases with information provision (as the probability of an ex post good news is low) and when effort decreases with information provision (as the probability of an ex post good news is high), information provision incentives decrease with the cost parameter.

Differentiating (6) with respect to *u* we get;

$$\frac{dF_i}{du} = \frac{Lx}{2}(2v-1)\left(\frac{2L_s + Lx(1-2v)}{c}\right)$$

We can therefore conclude that incentives to information diffusion decrease with *u*[11].

Turning to the consequences of changes in *x* we get:

$$\frac{dF_i}{dx} = \frac{L}{c}(2v-1)(u-1)\left(L_s + Lx(1-2v)\right)$$

We can conclude that $v < \frac{1}{2}$ is sufficient for $\frac{dF_i}{dx} > 0$, while if $v > \frac{1}{2}$ then $\frac{dF_i}{dx} > 0$ is a consequence of $\left(2L_s + Lx(1-2v)\right) < 0$, which is needed to have a strictly positive F_i (see footnote 21). In words, both when the effort increases with information provision (as the probability of an ex post good news is low) and when effort decreases with information provision (as the probability of an ex post good news is high), information provision incentives increase with the variability across good and bad news, as represented by parameter *x*. Indeed, the larger is the gap between private losses when the good or the bad state of the world are realized ex post, the larger will be the social value of information provision by the benevolent environmental authority.

Finally, focusing on the impact of changes in *v* we get:

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[11] Indeed, $\frac{dF_i}{du} < 0$ when $v < \frac{1}{2}$, as in this case $2L_s + Lx(1-2v) > 0$; on the other hand, $L_s < \frac{Lx}{2}(2v-1)$ when $v > \frac{1}{2}$ so that, again, $\frac{dF_i}{du} < 0$.

$$\frac{dF_i}{dv} = 2\frac{L}{c}x(u-1)\big(L_s + Lx(1-2v)\big)$$

As a result, the incentives towards information diffusion increase (decrease) when $\big(L_s + Lx(1-2v)\big) < 0$ (> 0). We can therefore conclude that $v < \frac{1}{2}$ is sufficient for $\frac{dF_i}{dv} < 0$, while when $v > \frac{1}{2}$, as a positive F_i requires $\big(L_s + Lx(1-2v)\big) < 0$, then $\frac{dF_i}{dv} > 0$.

Comparative statics results so far can be summarized in the following Proposition.

Proposition 2. *Incentives towards information diffusion*

(i) increase with the usefulness of information and with the gap between the good and the bad ex-post state of the world;

(ii) decrease with costs of effort;

(iii) increase or decrease with the social loss related to an environmental disaster depending on whether information brings good news with a low or a high probability;

(iv) decrease or increase with the probability of good news depending on whether information brings good news with a low or a high probability.

The results in parts (iii) and (iv) are a consequence of a trade-off faced by the benevolent environmental authority. This tradeoff, linked to the result previously reported in proposition 1, is a central result of our paper.

On one hand, information diffusion improves the decision making of the regulated agent; on the other hand, from Proposition 1 we know that the effort resulting from useful information diffusion may decrease the agent's effort in reducing the probability of an environmental disasters. For this reason, we get the counterintuitive conclusion that the environmental authority, though benevolent, may choose not to provide information in response to an increase in the social damage related to a potential environmental disaster.

Discussion and Concluding Remarks.

The management of natural disasters requires sharing of information. Risk and vulnerability can sometimes be reduced if there is an adequate means of predicting hazardous events. Since individuals are unfamiliar with weather forecasts and risk patterns, information is likely to affect their effort towards the reduction of the likelihood and expected impacts. However, as we show in our paper, information does not necessarily drive effort in the "right" direction. Indeed, in public information provision, public authorities have a trade-off between "transparency" and social welfare.

This paper proposes a two-stage model in which a benevolent planner has information about the impact of a catastrophic event and, in order to maximize social welfare, chooses whether to disclose such information (bearing a fixed cost) to individuals potentially affected by a natural disaster; individuals take information as exogenous and adjust the level of effort to reduce the expected loss from the disaster, on the basis of how good and how useful available news are.

Starting from the second stage of the model, we show that, interestingly, useful information featuring a high probability of good news ex post (i.e. that the impact of the disaster is more lenient than expected), let the effort vary negatively, as the expected loss from the disaster is lowered.

In the first stage, the public authority takes information disclosure decisions, with the aim to improve social welfare and taking in account the cost of disclosure and the nature (good/bad) of the news. The higher is the usefulness of the information and the good/bad news probabilities gap, the higher is the incentive to spread news; on the other hand, diffusion decreases with the cost of effort. Overall, information disclosure reduces social costs, but it can increase the expected losses in case of catastrophe. Therefore, the choice of the benevolent authority may be not to disclose information. This result is coherent with Goldstein and Leitner (2015), stating that the authorities have no incentive to spread information in favorable times. On the contrary, and differently from Angeletos and Pavan (2004), our results derives an equilibrium characterized by less transparency among agents.

Although we deem our contribution as novel and policy relevant, several improvements are indeed possible: these include the explicit modelling of a multi agent second stage where agents may free ride on each other's effort, as well as deriving model results in a more general implicit functional forms model. Straightforward future research efforts could also consider the possibility that not only information spreading, but also its acquisition is costly; finally, the explicit consideration of risk aversion and of the role of insurance markets may be a relevant extension of our work.

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