# *Keep calm and carry on*: A theory of governmental crisis communication*

Romain Bizet[†] Pierre Fleckinger[‡]

May 16, 2019

**Abstract**

This paper develops a model of strategic communication which questions how informed governments can credibly and effectively disclose warning information to exposed populations in the wake of major disasters. Credible public communication strategies take the form of severity scales whose optimal design hinges on the divergence between individual and social preferences, typically embodied by the existence of external effects of individual responses. Private and committed modes of communication are also investigated and shown to increase expected welfare. The paper also considers combinations of crisis communication with disaster management strategies. In particular, when ex post transfers are available - e.g. through public relief funds or emergency response plans - it is optimal for the government to subsidize pro-social actions and to provide partial public insurance when responses entail negative externalities. These transfers facilitate communication and improve response. Several policy aspects and applications of the model are discussed.

**Keywords**: Disaster, communication, cheap-talk, externalities.
**JEL codes**: D83, Q54, H84.

*Paul Schweinzer deserves very special thanks for inspiration.

[†]Corresponding author. MINES ParisTech, PSL - Research University, CERNA - Centre for Industrial Economics, i3, CNRS UMR 9217, `romain.bizet@mines-paristech.fr`, 60 boulevard Saint-Michel, 75006, Paris, France.

[‡]MINES ParisTech & Paris School of Economics, `pierre.fleckinger@mines-paristech.fr`.

# Contents


**1 Introduction** **3**

**2 Motivating examples** **7**

**3 A cheap-talk model of public disaster communication** **9**
- 3.1 The model . . . 9
- 3.2 Communication equilibria . . . 14
  - 3.2.1 Properties of communication equilibria . . . 14
  - 3.2.2 On the design of credible severity scales . . . 15
  - 3.2.3 Welfare analysis . . . 18

**4 Improving public communication through last-mile communication and commitment** **20**
- 4.1 Public versus last-mile communication . . . 21
- 4.2 The value of commitment . . . 24
  - 4.2.1 Committed public communication . . . 26
  - 4.2.2 Committed private communication . . . 26

**5 Global disaster management strategies: some coordination issues** **26**
- 5.1 The coordination of disaster communication with ex ante preparedness . . . 27
- 5.2 The coordination of disaster communication with ex post transfers . . . 29
  - 5.2.1 Partial public insurance and subsidies . . . 30
  - 5.2.2 On the use of disaster relief funds . . . 32

**6 Alternative specifications and interpretations of individual preferences** **34**
- 6.1 *Better safe than sorry*: the political economy of snowstorm communication . . . 34
- 6.2 Alternative micro-foundations . . . 36
- 6.3 Heterogeneous risk perceptions . . . 38

**7 Conclusion** **39**

**A Proofs** **41**

# 1 Introduction

This paper studies the strategies adopted by governments, public officials or health and safety regulators to communicate about major disasters. We consider harmful events during which the actions that individuals would like to take in order to protect themselves differ from those a planner would like them to take in order to minimize the adverse consequences of the event. This description applies to natural or technological disasters. Avoiding congestion during evacuations from wildfires or hurricanes, issuing vaccination or quarantine orders to contain epidemics, limiting access to retail bank desks after a financial crisis, or recommending people to stay home to avoid exposure to a nuclear fallout are cases in which the government tries to persuade individuals not to take an action they may have taken otherwise.

This credibility issue faced by governments has been extensively discussed in the crisis communication and management literature.[1] The central question raised by this literature is how informed parties can effectively convey credible information to exposed populations so as to limit the adverse consequences of major disasters. The main conclusion from this literature is the need for governments and policy makers to communicate credibly and truthfully during crises. This paper proposes a novel game-theoretical approach of this question, and tries to shed light on how to effectively communicate information during crises.

Our model is based on three main stylized facts. First, we argue that an important feature of these situations is the asymmetric information available to the parties involved. In the examples listed above, affected populations are usually uninformed of the specifics of the situation,[2] while governments may collaborate with local firms (e.g. the operator of a damaged polluting plant) or agencies (e.g. meteorological stations) to obtain relevant information regarding the severity of the incoming or ongoing disaster. In such cases, the response of the population crucially depends on the information communicated by informed authorities. Alarms or early warning

[1] A recent report by the Joint Research Centre of the European Commission provides a thorough review of this literature (Pljansek et al., 2017). Palttala et al. (2012) and Pljansek et al. (2017) document the credibility issues faced by informed parties when communicating about imminent crises, as well as the efficiency losses associated with the lack of trust of local populations towards official communication. To address this issue, Seeger (2006) suggests that governments should foster trust through honesty and empathy, rather than profit from short-term benefits obtained by downplaying risks. Cole and Fellows (2008) claims that *flexible communication* - i.e. differentiated communication strategies with each affected community - should be used to account for the heterogeneity of local sub-cultures towards catastrophic events. This literature has had an important impact on real crisis communication strategies. For instance, the U.S. Centers for Disease Control and Protection (CDC) uses the crisis communication framework initially proposed by Reynolds and Seeger (2005), whose best practices have been summarized by Seeger (2006). A review of this framework is available here: https://emergency.cdc.gov/cerc/ppt/CERC_Crisis%20Communication%20Plans.pdf

[2] In some situations, such as local natural disasters, the population can be aware of the disaster before authorities. This paper does not tackle these situations.

systems such as the Californian fire alert[3] system embody this need to communicate information to vulnerable populations.

Second, we assume the existence of a discrepancy between private and social preferences, and show that it may undermine communication. The informed party can be tempted to manipulate the information disclosed in order to avoid socially costly outcomes such as panic or congestion, while the uninformed population can anticipate this strategic behavior and choose to disregard the government's recommendation. One illustration of this credibility issue is the decision by Californian officials not to issue evacuation orders during the 2017 wildfire by fear of creating congestions on local highways. Multiple other disaster management case studies are reviewed in section 2.

Third, the key novelty in the present paper is the representation of credibility as an ex post incentive compatibility constraint within a cheap-talk game.

Our model involves a sender informed of the extent of a catastrophe (the government) who communicates publicly with a continuum of receivers equally exposed to harm, but characterized by heterogeneous costs of protection (the population).[4] The receivers' protective actions are characterized by positive or negative external effects. These external effects can either capture socially costly behaviors such as panic, or pro-social outcomes such as herd immunity. Possible distortions in communication root in these external effects. The key condition of incentive-compatibility of the messages sent in cheap-talk games mirrors exactly the central concerns of credibility and trust from the crisis management literature.

The equilibria of this game are structurally identical to the ones presented by Crawford and Sobel (1982) (CS in the following), and provide valuable insights on the optimal design of crisis communication strategies. First, their classical interval structure is consistent with the pervasive use of disaster severity scales. Second, these scales should not only be defined based on the severity of the underlying event, but also on the types of behavior the informed party seeks to induce. For instance, avoiding panic reactions by downplaying the risk does not appear as a credible communication strategy, while precautionary, or *better-safe-than-sorry* , strategies are shown to lead to pro-social behaviors. We finally show that transparency matters: when multiple public communication strategies can be sustained in equilibrium, the most informative strategy always yields the largest expected welfare.

[3]The Californian fire alert is a text messaging system designed to warn all cellular phones within a specific area of the risks associated with wildfires.

[4]Or, in other interpretations that we also discuss, heterogeneous perceptions of risk, heterogeneous propensities to shift political opinions or heterogeneous foregone economic opportunities.

Our main model describes public, non-committed communication. In a second step, we show how private communication and commitment can be used to improve crisis communication strategies. *Last-mile communication*, e.g. private communication between the government and local communities, allows the informed party to issue recommendations tailored to the needs of the population, which improves the aggregate response of the population and increases welfare. Committing to reveal information also improves welfare, although full revelation is never optimal. These two results mirror the conclusions of the crisis communication literature regarding the value of trust and transparency in crisis communication, but highlight some limits of transparency in crisis communication.

Next, we extend our game to study the coordination of crisis communication with disaster management efforts. We consider two types of efforts: ex ante *preparedness* [5] and *ex post* response. We show that preparedness improves welfare, but does not necessarily favor communication credibility. Reducing the negative externalities of individual responses - e.g. by building larger tsunami escape roads - aligns the incentives of the sender with those of the population, which increases equilibrium information disclosure. However, fostering positive externalities (e.g. through the promotion of more effective vaccines) shifts the incentives of the population away from those of the government, reducing its ability to disclose information in equilibrium.

Ex post transfers designed to curtail the consequences of a disaster - such as emergency response plans or disaster relief funds - are also shown to interact with the communication stage. Such transfers allow the sender to communicate more transparently with the receivers, and improve expected welfare. Optimal transfers entail the subsidy of protective actions characterized by positive externalities, and partial public insurance of victims under negative externalities. This analysis of the effect of committed transfers on the equilibria of cheap talk games is, to the best of our knowledge, new to the literature. It also contributes to the economic literature on disaster insurance and the Samaritan dilemma, according to which agents exposed to the risks of rare disasters choose suboptimal levels of self-protection because of the inability of governments to commit not too insure their losses (see e.g. Coate (1995); Kunreuther (1996, 2006); Kunreuther et al. (2013) or Teh (2017)). Our analysis provides a rationale for the commitment problem faced by the government: in the short-run, disaster insurance facilitates communication and improves the population's response to the disaster.

[5] Preparedness can be thought of as information campaigns that advertise proper emergency behaviors, such as seeking high-ground shelter during floods. The island-city of Dordrecht in the Netherlands, for instance, advertises high-ground shelter to its inhabitants in order to avoid congestion, as only 10-20% of its population can safely evacuate by land in case of severe floods.

The final section of this paper investigates alternative rationale for the discrepancy between private and social preferences. We show that heterogeneous risk perceptions and political costs associated with the negative consequences of extreme events can also lead to communication distortions. For instance, city officials often overreact to snowstorm forecasts, shutting down schools and public services despite the mild nature of the events faced.[6] Political costs associated with negligence accusations following the negative consequences of a snowstorm can lead policy-makers to adopt cautious attitudes, pooling together all snowstorms beyond a certain magnitude.

Besides its applied contribution, our paper also contributes to the literature on cheap-talk games. First, we provide an alternative micro-structure to the classical cheap-talk game proposed by CS, in which we introduce heterogeneous audiences while retaining the main equilibrium properties of the original uniform-quadratic cheap-talk game. In addition, contrarily to most models of expertise in which an expert tries to influence an exogenously biased policy-maker (e.g. Krishna and Morgan (2001, 2004); Che and Kartik (2009); Che et al. (2013)), the divergence of objectives between the sender and the receiver in our setting stems directly from the aggregation of individual preferences.[7]

Our model introduces a new type of cost heterogeneity in individual preferences: biases towards taking the socially optimal action are homogeneous while the private cost of taking this action varies across receivers. In this sense, our paper is related to the literature on public versus private modes of persuasion. Interestingly, we show that our setting generically features mutual subversion, which differs from the classical mutual discipline insight (see e.g. Farrell and Gibbons (1989) or Goltsman and Pavlov (2011)). As a result, private communication dominates public communication. This relates to the findings of Koessler (2008) regarding certifiable communication and lobbying, and is due to the nature of the heterogeneity of receivers.[8] This introduction of heterogeneity also differs from the usual multidimensional cheap-talk literature (see e.g. Battaglini (2002)), as we enrich the dimension of the CS cheap talk game by adding receivers of various types, but reduce the action space to a binary decision and consider a one-dimensional relevant state-space.[9]

[6] ADD FOOTNOTE HERE

[7] This feature is also present in the global game approach of coordination frictions proposed by Lukyanov and Su (2017).

[8] Our analysis is restricted to the case of non-committed communication, but the existing literature has also tackled committed public persuasion (see e.g. Wang (2015); Laclau and Renou (2016); Gardete and Bart (2017)).

[9] Additionally, our model is close to Allon et al. (2011), who analyze the provision of information by firms to queuing customers, using a binary action model characterized by external effects. In their paper, customers choose whether to queue, thus affecting the expected waiting time for others. Our model differs as we explicitly deal with the heterogeneity of receivers, and as individual actions and states of nature constitute two different dimensions. Our model can also be related to Kawamura (2011), who studies binary communication strategies adopted by multiple senders to influence a single decision maker in the context of public consultation procedures.

This paper is organized as follows. Section 2 describes some motivating examples. Section 3 presents the game and its equilibria. Section **??** discusses how private communication and commitment from the informed party can be used to improve crisis communication. Section 5 presents extensions of the model that address the coordination of disaster communication with preparedness and disaster response. In particular, subsection 5.1 studies the effect of ex ante investment in preparedness on the equilibria of the cheap-talk game, while subsection 5.2 explores the possibility for the sender to engage in various types of ex post transfers, and characterizes their effect on communication equilibria. Section 6 presents additional extensions of the model. Section 7 concludes.

## 2 Motivating examples

**Example 1.** *Hurricanes and floods*

Hurricane evacuation policies illustrate the discrepancies that can arise between socially and privately optimal responses to a disaster. In 2005, hurricane Rita caused the death of a hundred and eighteen people in Texas, sixty of which occurred during the evacuation process. Therefore, in 2017, the guidelines issued by the State of Florida in prevision of hurricane Irma were partly designed to limit congestion and the exposure of the evacuating population. In particular, the sick and those with limited mobility were advised not to evacuate, and sheltered within local hospitals. Likewise, those who had not fled Miami by the day preceding the arrival of the hurricane were advised not to do so, and to take shelter in their homes.[10]

An important aspect of this literature is the necessity to address crises by providing exposed populations with recommendations, such as stockpiling food and water, seeking for immediate shelter or evacuation orders. However, although credibility is recognized by this literature as a key feature of crisis communication, only few insights have been suggested regarding how a communication strategy can be made credible. For instance, the CERC model proposed by (insert reference here) identifies credible communication as empathy and openness towards exposed population (Cole and Fellows, 2008).

**Example 2.** *Wildfires*

Californian wildfires provide another compelling example of the discrepancy between privately and socially optimal disaster responses. They also illustrate how this discrepancy can

Finally, our model is also related in spirit to the political science literature in which cheap-talk has been used to model diplomatic negotiations and conflict resolution between countries (Trager, 2010; Ramana, 2011).

[10] See e.g. http://www.slate.com/blogs/the_slatest/2017/09/09/the_people_who_won_t_or_can_t_flee_irma.html.

influence the decisions made by informed authorities regarding what information they communicate to exposed populations.

On October 9th, 2017, local authorities from the Sonoma county decided not to use an early warning system (EWS) designed to warn local populations of the vicinity of the fire by means of an evacuation text message. While locals and some newspapers accused the authorities of negligence,[11] local officials in charge of this decision explained that the use of the EWS would have put thousands of people at risk by preventing the arrival of fire-fighters. Two months later, the state of California activated this same disaster alert system to warn 22 million Californians of an increased overnight fire risk. The text message read: "*Strong winds overnight creating extreme fire danger. Stay alert. Listen to authorities.*".

Other cases of wildfires have been documented by Steelman and McCaffrey (2013). These examples illustrate how the discrepancy between privately and socially optimal actions can lead public authorities to distort communication and withhold information. They also illustrate the relevance of the incentive compatibility constraint concept to capture the credibility issues faced by informed parties during crises. An early warning system designed ex ante in order to disclose information to a population can be disregarded ex post if it does not allow to tailor the communication to the objective of the informed party, conditionally on the information available. Sending a public evacuation order to the population of exposed counties raises a sufficiently strong conflict of interest to deter public authorities from using an available communication channel to disclose available information.

**Example 3.** *Epidemics*

In the previous examples, communication is hampered by the existence of a social cost associated with the actions individuals would have probably taken if they had been informed of the incoming catastrophe. On the contrary, in the case of epidemics, the actions that individuals can take often entail positive externalities. Vaccinations, quarantines or the destruction of contaminated livestocks not only limit the risks borne by the individuals engaging in these actions, but also those borne by others.

However, a discrepancy between private and social objectives also arises in this context, as the actions listed above entail private costs which may disincentivize pro-social actions. Vaccines may entail rare side-effects, quarantined populations may be more likely to contract a severe

[11] See e.g. the following press articles covering the event: https://www.washingtonpost.com/investigations/the-only-california-county-that-sent-a-warning-to-residents-cellphones-has-no-reported-fatalities/2017/10/13/b28b5af4-b01f-11e7-a908-a3470754bbb9_story.html or https://www.nytimes.com/2017/10/13/us/california-wildfires-victims.html.

disease, and killing livestocks causes economic losses for stockbreeders. Hence, the private decisions regarding vaccinations or similar health-related measures will lead to sub-optimal adoption if individuals disregard the social benefits of their actions.

This issue, and the particular case of compulsory vaccination programs, have been studied in the economics literature (see e.g. Brito et al. (1991); Geoffard and Philipson (1997); Bauch and Earn (2004); Heal and Kunreuther (2005)). However, to the best of our knowledge, our approach is novel in the sense that we consider this case through the communication lens, and question how governments can persuade populations to engage in these pro-social actions without resorting to binding policy instruments such as mandatory vaccination programs.

**Example 4.** *Snowstorms*

Finally, snowstorms are another case in which informed authorities need to communicate with exposed populations about incoming hazards. In particular, anecdotal evidence from past snowstorm cases suggests that city officials tend to overreact to incoming snowstorms, recommending populations to stay home, shutting down essential public transportation services, and engaging in costly snow removal services even under apparently mild temperatures or snowfalls.

As the externalities associated with individual responses to snowstorms are unclear, this paper provides a rationale for these observation based on the assumption of the existence of political costs associated with snowfall damage. As a result of these political costs, elected officials adopt pooling strategies that confound all snowstorms of large magnitudes. In this case, the preferred approach of the policy-maker is consistent with a form of *precaution*, and the related communication strategy adopted will be referred to in the paper as a *better-safe-than-sorry* communication strategy.

# 3 A cheap-talk model of public disaster communication

## 3.1 The model

The game aims to capture the interaction between a benevolent government informed of the intensity of an incoming catastrophe with a population characterized by an homogeneous exposure to harm and heterogeneous costs of avoiding harm. In addition, the response of the population induces a social cost that the government would like to prevent (e.g. panic) or encourage (e.g. herd immunity). In order to adapt the response of the population to the severity of the incoming disaster, the government can publicly communicate with the population, and aims to convince an appropriate fraction of the population to take a protective action.

The timing of the game is as follows. First, nature draws the state of the world $r \in [0;1]$. $r$ is uniformly distributed over the unit interval, and represents the magnitude of an incoming disaster. The government (or sender, or S, or she in the following) privately observes $r$ at no cost. After observing $r$, the government can send an unverifiable public message perfectly observed by a population exposed to the disaster, and represented as a continuum of receivers of type $\theta$ uniformly distributed over $\Theta = [0;1]$. Each receiver in the population is aware of its type but is uninformed of the extent of the incoming catastrophe.[12] Upon reception of the public signal, receivers update their prior over the state space, and choose a binary protective action $a \in \{0;1\}$. Finally, payoffs are realized.

In contrast to classic cheap talk games, we assume that the sender chooses the message space $\mathcal{M}$ at an ex-ante stage. Later, only messages from $\mathcal{M}$ can be sent. This is meant to capture how alert scales are defined in reality.[13] This also solves the issue of multiple equilibria,[14] since it equips the government with a selection device to pick the equilibrium with the highest expected welfare ex ante. We assume that it is technically possible for the government to choose a rich enough set $\mathcal{M}$ to truthfully disclose the state of the world $r$. This is consistent with existing disaster response plans, which entail guidelines for communication such as sirens, radio and TV broadcasts, or severity scales.[15] Figure 1 summarizes the timing of the game.

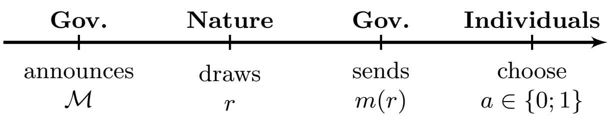


Figure 1: Timing of the game

For any individual of type $\theta$, seeking protection (i.e. choosing $a = 1$) entails a private cost $\theta$. Additionally, the aggregate response of the population, noted $\bar{a} = \int_0^1 a(r,\theta)d\theta$, is assumed to cause an external effect of intensity $\gamma\bar{a}$. Depending on the sign of $\gamma$, this external effect can be

[12] Here, we implicitly assume that a catastrophe is the result of a compound lottery, in which a first stage determines whether or not a catastrophe takes place, and a second stage determines its intensity. The population is thus aware of the result of the first stage, but uninformed of the result of the second stage of the lottery. In practice, a population living near a nuclear station may hear a large noise, suggesting that something happened at the plant. However, the population is generally unable to infer from the noise the severity of the situations developing at the plant.

[13] As argued repeatedly in the crisis management literature, receivers should be aware and understand the messages used by authorities. In the words of Cole and Fellows (2008) in analyzing the case of Hurricane Katrina, "message preparation before the crisis is essential" (p.224).

[14] It is well-known for instance that any cheap talk game features a babbling equilibrium, in which the receiver does not pay attention to the messages sent, and the sender always sends the same message. Moreover, language and meaning are arbitrary, and defined only in equilibrium in a classic cheap talk game. Beyond being realistic, our assumption does in some sense resolve these two issues at once.

[15] For instance, the nuclear regulatory commission considers 4 types of local alerts in case of of emergency in a nuclear power station. Likewise, the Richter and Saphir-Simpson scales allow authorities to provide information to population regarding earthquakes and hurricanes.

thought of as a negative externality due to panic or congestion, or as a positive externality due to the herd immunity effect of vaccinations. The preferences of any receiver can be represented by a utility function $u_R$, described in equation (1).

$$u_R(r,\theta,a,\bar{a}(r)) = \begin{cases} -r+\gamma\bar{a}(r), & \text{if } a=0 \\ -\theta+\gamma\bar{a}(r), & \text{if } a=1 \end{cases} \tag{1}$$

In equation (1), the state of nature $r$ characterizes the loss incurred by each individual when failing to seek protection from the disaster. Conversely, $\theta$ represents the private cost of seeking protection from harm. This specification of individual preferences assumes that all receivers are equally exposed to harm, but have heterogeneous costs of protection, perhaps because they have different (exogenous) insurance coverage, or different occupations implying different foregone opportunities, or simply because they have different possibilities or accesses to protection technologies.[16]

The sender is assumed to be a benevolent social planner, whose objective is to maximize welfare, defined as the aggregation of individual utilities:

$$W(r) = \int_0^1 u_R(r,\theta,a)d\theta \tag{2}$$

Letting $\Theta_0(r) = \{\theta : a(r,\theta) = 0\}$ be the set of types of receivers who choose $a = 0$, $\Theta_1(r) = \{\theta : a(r,\theta) = 1\}$ the set of individuals who choose $a = 1$, and $|| \ \Theta_i \ || = \int_{\Theta_i} f(\theta)d\theta$, equation (2) boils down to:

$$W(r) = \gamma \ || \ \Theta_1(r) \ || - r \ || \ \Theta_0(r) \ || - \int_{\Theta_1} \theta d\theta \tag{3}$$

Under complete information regarding the value of $r$, a receiver of type $\theta$ chooses $a = 1$ if and only if $u_R(r,\theta,1,\bar{a}(r|a=1)) > u_R(r,\theta,0,\bar{a}(r|a=0))$. This is equivalent to $\theta < r$, as the decision of receiver $\theta$ is without consequences on the aggregate response.[17] The weight of any individual on the aggregated external effect being null, only the damage due to the catastrophe and the private costs of protection are taken into account by individuals when choosing whether

[16] Alternative specifications of individual preferences are presented and discussed in section 6. In particular, $\gamma$ can also be interpreted as political costs associated with the management of disasters, as heterogeneous risk perceptions, or as an asymmetric externality induced by the actions taken by one group of receivers on itself or on the other group. In addition, the interpretation of $\theta$ and $r$ can easily be interchanged so that the model captures a case in which individuals are heterogeneously exposed to a known private harm (where private damage are captured by $\theta$), and where a protective action entails random consequences $r$. While this second interpretation may be relevant in the context of health treatments for instance, we do not pursue it in this paper.

[17] In other words, we have $\bar{a}(r|a=1) = \bar{a}(r|a=0)$ because of the assumption of a continuum of receivers.

to respond to the incoming disaster.

On the other hand, equation (3) shows that $\gamma$ appears in the optimization program of the sender. Hence, under asymmetric information, the sender can design a communication strategy, i.e. a mapping from the set of states to a set of public signals $\mathcal{M}$. As communication is public, we note $m(r)$ the message sent by the sender after observing $r$. Conditionally on the information revealed by the sender, receiver $\theta$ seeks protection if and only if the private cost of avoiding harm is lower than the expected damage incurred, obtained by revising the prior according to Bayes rule:

$$a(r, \theta) = 1 \Leftrightarrow \mathbb{E}(r|m(r)) > \theta. \tag{4}$$

As receivers share a common prior regarding the value of the random variable $r$, condition (4) implies that the profile of individual actions resulting from the public communication game can be described by a cut-off function $\theta^\star(r) = \mathbb{E}(r|m(r))$ such that action $a = 1$ is chosen in state $r$ by all receivers whose type $\theta$ is lower than $\theta^\star(r)$, while all receivers whose type is larger than $\theta^\star(r)$ choose action $a = 0$. In the hurricane example, equation (4) claims that people choose whether to abandon their homes by comparing the (possibly non-monetary) costs associated with staying home to those associated with fleeing.

In addition, we assume that communication is non-committed and payoff-irrelevant. Payoff-irrelevance seems legitimate as disaster communication strategies usually benefit from traditional communication infrastructures, such as TV, radio or telecommunication channels, and the cost of sending signals to the population is unlikely to play a significant role in the decision of public authorities. On the other hand, the absence of commitment of the informed party means that, once faced with an incoming disaster, the sender will do whatever she can to minimize its consequences. In particular, in any state of nature, if the informed party chooses to randomize over several possible messages, these messages must lead to the same ex-post level of welfare, and hence to the same equilibrium outcome. This is a strong assumption that defines a cheap-talk game, and departs from the committed persuasion literature.[18]

As usual in cheap-talk games, the message space is irrelevant, and only the mapping between states of the world and the actions chosen by the receivers is necessary to characterize an equilibrium. The message function chosen by the sender is equivalent to providing a recommendation regarding the equilibrium outcome, such as: *"given the information we have, we recommend that*

[18] In general, committed communication strategies can improve expected welfare, but require the informed party to be able to commit to choose a communication strategy which may be suboptimal ex-post in some states of the world (see e.g. Kamenica and Gentzkow (2011)).

*all individuals below type $\theta^\star$ seek shelter"*. This is consistent with disaster management practices enacted in Florida in 2017 in preparation for Hurricane Irma. Although over 5 million people were ordered to evacuate, some people such as hospital patients with limited mobility were not evacuated, and civil servants such as policemen or fire-fighters were not allowed to evacuate.[19]

In the following, we abuse notation and refer to $\theta^\star(r)$ as the best-response of the population when the sender chooses the communication strategy $m(r)$. Then, the welfare associated with the state of nature $r$ and communication strategy $m(r)$ is:

$$W(r) = \gamma\theta^\star(r) - r(1-\theta^\star(r)) - \frac{\theta^\star(r)^2}{2} \tag{5}$$

The three terms on the right hand side of equation (5) are intuitive: $\gamma\theta^\star$ represents the aggregate social cost of the population's response, it is negative when the external effect $\gamma$ is negative, and positive otherwise. The term $r(1-\theta^\star)$ represents the aggregate damage caused by the disaster upon the part of the population which could not or chose not to respond, and the final term $\frac{\theta^{\star 2}}{2}$ represents the aggregate private costs associated with the response of the population. Finally, ex ante expected welfare is defined as $\mathbb{E}W(\gamma) = \int_0^1 W(r)dr$. The following lemma describes two useful benchmark cases: the full information and first-best scenarios:

**Lemma 0.** *Expected welfare levels under full information and in the first-best scenario are:*

$$\mathbb{E}W_{Full}(\gamma) = \frac{\gamma}{2} - \frac{1}{3} \tag{6}$$

$$\mathbb{E}W_{FB}(\gamma) = \begin{cases} \frac{(1-\gamma)^3}{6} + \gamma - \frac{1}{2}, \ \textit{if}\ \gamma \geq 0 \\ \frac{(1+\gamma)^3}{6} - \frac{1}{2}, \ \textit{if}\ \gamma < 0 \end{cases} \tag{7}$$

*Proof.* All proofs are gathered in appendix A. □

Given the linear structure of individual preferences, aggregating individual utilities yields a uniform-quadratic cheap-talk game with constant bias. In particular, equations (4) and (5) show that while individuals whose type $\theta$ are smaller than $r$ would like to take action 1, the external effect of these actions leads the sender to prefer individuals with type $\theta$ inferior to $r+\gamma$ to adopt action 1. Our setting thus endogenizes the bias in the communication game, which is the result of the aggregation of individual preferences by the sender.[20] The next paragraphs

[19] This piece of anecdotal evidence is documented in two press releases in the New York Times and Slate.

[20] It could be argued here that the bias is due to the continuum nature of our population. With a population of $N$ receivers and an external effect proportional to the average response, there would be a comparable external effect of individual responses, as each receiver would only be bear a fraction $\gamma/N$ of the consequences of its own response.

show that the equilibria of this game are structurally identical to those presented in Crawford and Sobel (1982), and analyze the new implications that can be drawn in the context of disaster communication strategies.

## 3.2 Communication equilibria

### 3.2.1 Properties of communication equilibria

In the following, and without loss of generality, we focus on pure communication strategies. The solution concept used to solve the game is Bayes-Nash equilibrium. Given a message function $m : [0;1] \to \mathcal{M}$ and any state of nature, the sender must be *credible* : she must have no incentives to deviate from the communication strategy chosen $m(r)$. Hence, $m$ has to satisfy the incentive compatibility condition:

$$\forall r \in [0;1],\ m(r) \in \underset{m(r')}{\operatorname{argmax}}\, W(r, \theta^\star(m(r'))). \tag{8}$$

Conditionally on a credible message $m(r)$ sent by the sender, each receiver chooses an action that maximizes his expected pay-off in equilibrium:

$$a(r,\theta) = \underset{a}{\operatorname{argmax}}\, \mathbb{E}\left[u_R(r,\theta,a,\bar{a})|m(r)\right]. \tag{9}$$

A first important remark is that the full information benchmark mentioned in lemma 0 is not incentive compatible. Indeed, when $\gamma \neq 0$, the response of an individual $\theta$ to a fully revealing strategy would be to choose $a = 1$ when $\theta < r$. In turn, the sender has an incentive to deviate from truth-telling by claiming $r + \gamma$, which violates equation (8). As was stressed in example 2, this ex post incentive compatibility constraint captures the fact that communication decisions are made *after* observing the severity of the catastrophe, and constitutes the fundamental contribution of this paper to the study of crisis communication strategies.

We now look for strategies that satisfy the incentive compatibility constraint. Notice first that our game always admits a babbling equilibrium. In this equilibrium, the sender sends a single message, irrespective of the state of the world. This equilibrium is uninformative, as each receiver can do no better than reacting according to the common prior. All receivers of type $\theta < \frac{1}{2}$ play action $a = 1$ whereas receivers of type $\theta > \frac{1}{2}$ play action $a = 0$.[21]

[21] After the Fukushima-Daiichi nuclear accident, the absence of communication from the government during the days that followed the catastrophe led people to make unfortunate decisions, leading to excessive exposures to radiations or psychologically-driven migrations (see e.g. Figueroa (2013) or Zhang et al. (2014)). Perko (2011) provides additional pieces of evidence of the adverse effects of the distrust of populations in their governments

The babbling equilibrium of this game can be thought of as a case in which the government chooses not to disclose any information to the exposed population, or in which all telecommunication lines have been disabled. In these cases, people have no outside information regarding the extent of a catastrophe, and can only base their decision on their prior and their own private cost of taking protective actions.

The expected welfare associated with the babbling equilibria is $\mathbb{E}W_{bab}(\gamma) = \frac{\gamma}{2} - \frac{3}{8}$. Expected welfare under babbling is thus strictly lower than the full information welfare presented in equation (6). An important question is thus whether an informed government can, in the absence of commitment, do better than this uninformative equilibrium.

### 3.2.2 On the design of credible severity scales

We now look for equilibria in which the sender transmits information to the receivers. To do so, we say that a communication strategy $m(r, \theta)$ is *monotonic* if, for all $r$, there exists a cut-off type $\theta^\star(r)$ separating 0-reponders from 1-responders and such that $\theta^\star(r)$ is non-decreasing in $r$. Using this definition, proposition 0 states the main properties of public communication equilibria:

**Proposition 0.** *Communication equilibria are necessarily monotonic and only involve a finite number of messages.*

Hence, if a communication equilibrium exists, there must exist $n \in \mathbb{N}$ such that the equilibrium consists of an increasing set of cut-offs $(\theta_i^\star)_{1\leq i\leq n}$, respectively induced over intervals of the state space noted $[r_{i-1}; r_i]$, for all $i \leq n$, $i \neq 0$, and where $r_0 = 0$ and $r_n = 1$. The babbling communication strategy described above corresponds to the case $n = 1$. The following paragraphs focus on solutions with $n > 1$.

An increasing sequence of equilibrium outcomes $(\theta_i^\star)_{1\leq i\leq n}$ and a set of associated intervals defined by a sequence of thresholds $(r_i)_{0\leq i\leq n}$ constitute an equilibrium if and only if they satisfy the sender's incentive compatibility constraint, and the receivers' Bayesian rationality constraint. The latter requires that conditionally on receiving a credible message over any interval $[r_{i-1}; r_i]$, the public belief obtained by Bayes' rule is uniform over this interval. Then, any equilibrium outcome has to satisfy the following necessary condition:

$$\forall r \in [r_{i-1}; r_i], \theta^\star(r) = \theta_i^\star = \frac{r_{i-1} + r_i}{2}. \tag{10}$$

based on a case study of the Three-Mile Island accident, which was followed by a massive panic reaction from the population living near the power station.

In addition, thresholds $(r_i)_{0<i<n}$ and equilibrium outcomes $(\theta_i^\star)_{1\leq i\leq n}$ have to satisfy the sender's incentive compatibility constraint:

$$\forall i < n,\ W(r_i, \theta_i^\star) = W(r_i, \theta_{i+1}^\star). \tag{11}$$

Developing equation (11) using equations (10) and (5) yields the following condition:

$$\forall i < n,\ r_{i+1} - r_i = r_i - r_{i-1} + 4\gamma. \tag{12}$$

Condition (12) is identical to the findings of CS. From this condition, corollary 1 characterizes all the equilibria of the game.

**Corollary 1.** *For all values of $\gamma$, and all $n \in \mathbb{N}$, there exists a unique equilibrium characterized by $n$ equilibrium outcomes $(\theta_i^\star)_{1\leq i\leq n}$ and $n+1$ thresholds $(r_i)_{0\leq i\leq n}$ if and only if $|\gamma| < \frac{1}{2n(n-1)}$. In addition, we have that $\forall i \leq n$, $r_i = \frac{i}{n} - 2\gamma i(n-i)$, and $\theta_i^\star$ is induced over $[r_{i-1}; r_i]$.*

Hence, for any value of $\gamma$, there is a finite number of equilibrium communication strategies, involving from 1 to $N(\gamma)$ equilibrium outcomes. It also appears that under either positive or negative externalities, informative public communication is impossible when $|\gamma| > \frac{1}{4}$. When preferences are sufficiently biased, the government can do no better than silence. Conversely, when informative communication strategies can be adopted in equilibrium, the sender can define a finite number of messages corresponding to a range of possible catastrophes of similar severity. The maximum quantity of information disclosed by the sender in equilibrium depends on the extent of the external effects of individual actions. In particular, the lower these external effects, the more informative the government's communication strategy can be.

This casts a new light on the incentives faced by governments or institutions engaging in disaster communication. When facing the possibility of socially costly reactions, it appears that the informed party has no incentives to downplay the risks systematically. Doing so would result in a proportional adaptation of the response of the population, and to a loss of welfare. The optimal structure of the equilibria of the communication game suggests the use of *vague* communication strategies, pooling catastrophes of different magnitudes to foster socially optimal behaviors while remaining credible.

Figure 2 illustrates these communication strategies. In particular, an interesting feature of these strategies clearly appears: the structure of the optimal message scale changes with the sign of the external effects of individual actions. Under positive externalities, the width of the

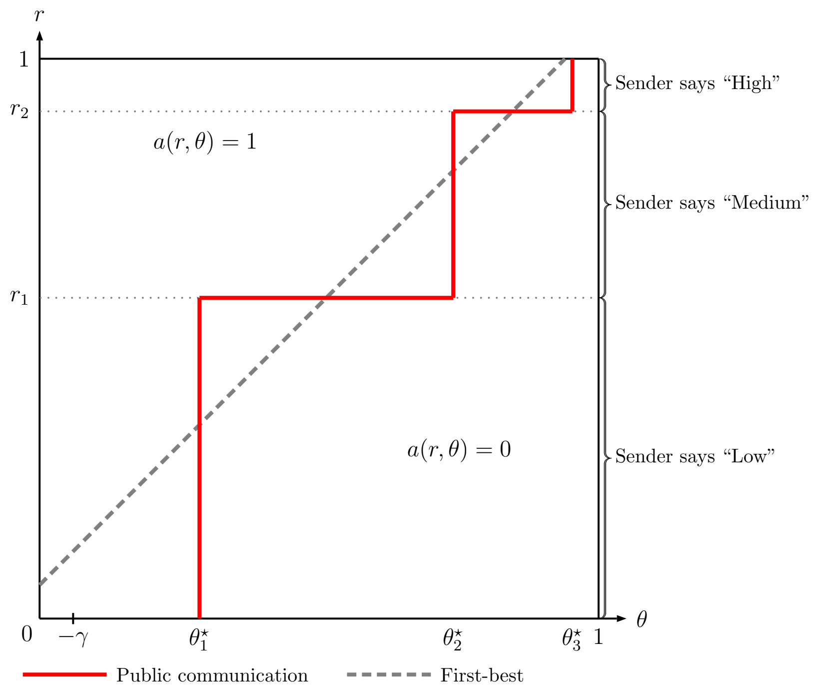


Figure 2: The three-message equilibrium strategy when $\gamma = -0.06$.

partition of the state space increases when the catastrophe worsens. Under negative externalities, the partition of the state space is more narrow when catastrophe are more severe.

These communication strategies are consistent with the pervasive use of severity scales. The U.S. CDC defines a severity scale based on the expected mortality of pandemics, whose increasing steps are consistent with the pro-social action case.[22] Likewise, the U.S. Nuclear Regulatory Commission (NRC in the following) defines four emergency messages to warn populations after abnormal events in nuclear power stations, whose decreasing steps[23] are consistent with the panic deterrence cases. Similar severity scales are used to signal other types of rare disasters. Examples of such severity scales include fire alarms, which can be considered as a two-step severity scales, or the Saphir-Simpson scale, which contains five wind speed categories in order to communicate hurricane risks.

The optimal design of disaster communication strategies hence requires to account for both the severity of the event and the external effects of individual responses. The model suggests that governments should pool extreme events when issuing recommendations regarding pro social

[22] See e.g. https://en.wikipedia.org/wiki/File:CDC_Pandemic_severity_index.png.

[23] The most benign events are communicated in *notifications of unusual event*, while larger incidents are communicated through an *alert*. The most severe events are communicated as *site area emergencies* and *general emergencies*. Though, the probabilities associated with events of each category are decreasing, e.g. most events communicated fall under the first category, and hardly any event has ever been communicated using other categories.

actions and pool mild events when trying to avoid socially costly behaviors. The first part of this result suggests that precaution in crisis communication, i.e. pooling together the worst events, fosters pro-social behaviours. The intuition guiding this result is directly related to the credibility of public communication strategies. Under positive externalities, receivers expect the sender to over-report the risks associated with a given event, leaving her no other choice than to reduce the quantity of information disclosed regarding high states by pooling them together. Likewise, under negative externalities, receivers expect the sender to downplay the risks, which requires the informed party to provide more information regarding severe events to restore credibility.

Regarding external validity, our main qualitative result is general: communication strategies should resemble severity scales, and pool together events of similar nature. However, the quantitative result does rely on the uniform distribution of individual types: under a different distribution, the volume of the sets of states pooled would depend on both the severity of the event and the density of population characterized by a given private cost of protection. Though, this result underlines the importance of designing severity scales designed not solely based on the magnitude of the underlying event but that also account for the individual behaviors induced and their social costs.

#### 3.2.3 Welfare analysis

We now turn to the analysis of the expected welfare associated with any given communication strategy. In particular, for all values of $\gamma$, we refer to the equilibrium characterized by the largest number of equilibrium messages as the *most informative equilibrium*.

Formally, for a given strategy involving $n$ distinct messages, we have:

$$\mathbb{E}W(n,\gamma) = \sum_{i=1}^{n} \int_{r_{i-1}}^{r_i} \left( \gamma\theta_i^\star - r(1-\theta_i^\star) - \frac{\theta_i^{\star 2}}{2} \right) dr. \tag{13}$$

Corollary 2 presents the explicit form of $\mathbb{E}W(\gamma)$ for any $\gamma$ and all associated communication equilibria. Calculations are omitted.

**Corollary 2.** *For any $\gamma$, the expected welfare associated with an existing $n$-message equilibrium admits a closed-form solution presented in equation (14), which is maximized under the most informative equilibrium:*

$$\mathbb{E}W(n,\gamma) = -\frac{\gamma^2(n^2-1) - 3\gamma + 2}{6} - \frac{1}{24n^2} \tag{14}$$

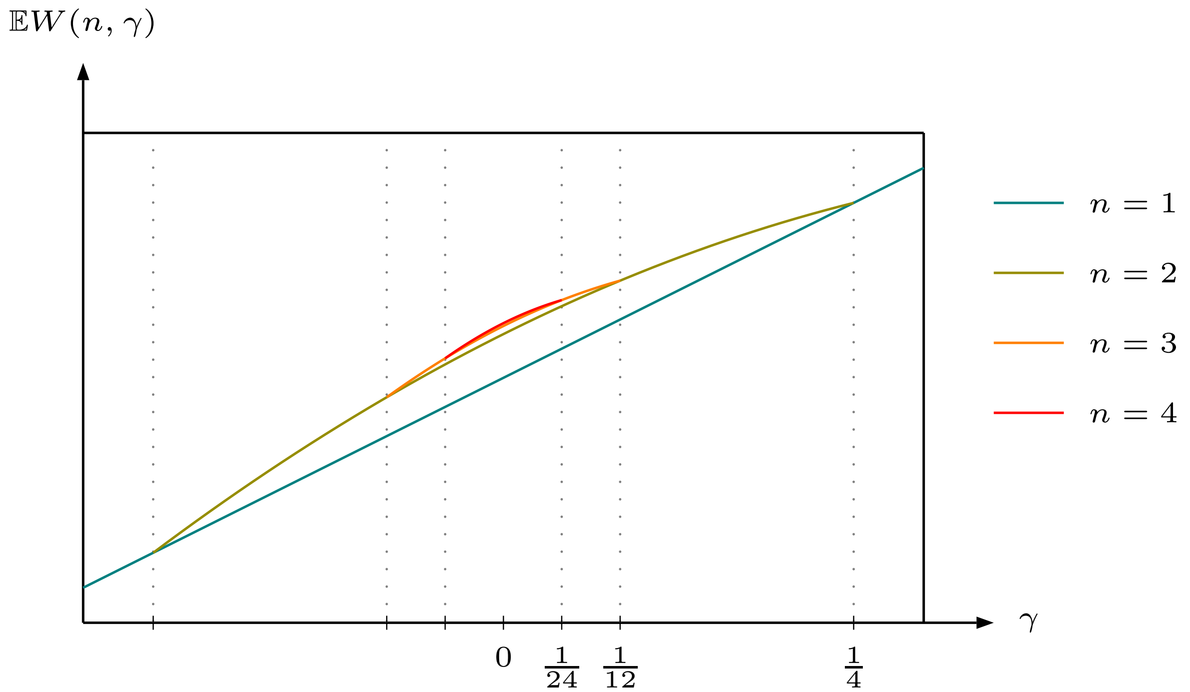


Figure 3: Expected welfare for communication equilibria for $n \leq 4$ and $\gamma \in [-0.3; 0.3]$.

The expected welfare associated with credible communication strategies available when $\gamma \in [-0.3, 0.3]$ and $n < 5$ are plotted on figure 3.

The more informative the communication strategy chosen in equilibrium, the larger the expected welfare. This result is conform to the original findings of CS. In particular, this result implies that if receivers were to vote behind the veil of ignorance - before learning their own type - on the communication strategy the sender should adopt in case of emergency, they would unanimously agree to rely on the most informative communication strategy. This interpretation is consistent with our catastrophe setting, as disaster communication plans and mitigation strategies are usually determined ex ante, when people do not know when a catastrophe will strike, nor how able they will be to avoid it when it occurs. This result provide strong support for choosing an equilibrium selection criterion which singles out the most informative equilibrium (see e.g. Chen et al., 2008).

Note however that the structure of individual preferences leads to new insights at the interim stage. When they know their types, but before learning the message sent by the government, some individuals might be strictly better-off knowing that a sub-optimal message scale is being played by the government. In particular, it is clear from the previous analysis that any individual whose type corresponds to an equilibrium outcome $\theta_i^{\star}$ of a given message scale can play his preferred action (state-wise) if that message scale is used. In particular, it can be shown that the interim expected utility of a receiver $\theta$ is given by the following expression, where index $p(\theta)$ is such that $a(r,\theta) = 0$ if and only if $r < r_p$.[24]

$$
\begin{aligned}
\mathbb{E}_r u_R(\theta) &= \int_0^1 u_R(r,\theta,a(r,\theta),\bar{a}(r))dr && (15)\\
&= \sum_{i=1}^{p} \int_{r_{i-1}}^{r_i} u_R(r,\theta,0,\gamma\theta_i^\star)dr + \sum_{i=p+1}^{n} \int_{r_{i-1}}^{r_i} u_R(r,\theta,1,\gamma\theta_i^\star)dr && (16)\\
&= -\frac{r_p^2}{2} + \gamma - \theta(1-r_p) && (17)
\end{aligned}
$$

This expression is clearly maximum the closer $r_p$ is from $\theta$. Hence, in a hypothetical world in which receivers would vote at the interim stage for two competing (informative and credible) communication strategies, it is unclear which scale would obtain the largest support from the population. In particular, one can find instances in which, in a contest between two credible message scales, the least informative scale would obtain the largest support. From a political economy perspective, this result calls for the clear design of disaster severity scales well before disastrous situations arise. Indeed, failing to do so exposes the government to potential lobbying from the population in order to deviate from the socially optimal communication strategy.

In the following, we consider that conditionally on the value of $\gamma$, the most informative equilibrium is always selected.

# 4 Improving public communication through last-mile communication and commitment

This section investigates two ways of improving public communication. First, we look at private or *last-mile* communication and show that, contrarily to the general intuition of cheap-talk games, our setting generally features mutual subversion. This result confirms the recommendations to avoid one-size-fits-all strategies and to tailor recommendations to the specific exposure and needs of local populations, as advocated in the crisis communication literature.

Second, we consider how commitment can affect optimal communication strategies. In the public communication game, commitment allows the full revelation of information and increases welfare. Committing to transparently disclose information during crises thus appears as a sound

[24] In other words, $r_p$ is the lowest cut-off of the communication strategy where messages sent by the sender for larger states induce $\theta$ to play action 1.

objective. In the private communication game, commitment also allows the sender to persuade a larger proportion of the population to take the first-best action, although the optimal communication strategy is not truthful.

### 4.1 Public versus last-mile communication

So far, we have assumed that the sender could only engage in public communication. We now relax this assumption and examine the possibility of private communication between the informed party and each member of the vulnerable population.

The analysis of private modes of disaster communication serves multiple purposes. First, the development of digital early warning systems makes it easier and easier for governments to tailor their communication strategies to the various needs of exposed populations. However, it is unclear how this additional degree of freedom can serve the purpose of the (benevolent) government. Indeed, as the public/private communication literature has shown, the ability to communicate in public need not be related to the ability to communicate in private. Cases of mutual discipline in which public communication is more informative than private communication are common in these games (see e.g. Farrell and Gibbons, 1989; Goltsman and Pavlov, 2011).

Second, *last-mile communication* has been strongly advocated for by the crisis management literature (see e.g. Pljansek et al., 2017; Steelman and McCaffrey, 2013), which argues that accounting for the specificities of local sub-cultures - i.e. levels of familiarities with the disaster and abilities to respond to it - would greatly improve a population's response. This section thus offers a theoretical analysis of this alternative mode of communication, to serve as a possible additional rationale in favor of this recommendation.

Here, we ask whether it makes sense for a government to engage in private communication with different populations affected by a catastrophe instead of communicating publicly with all the relevant parties. To do so, assume that the sender can use private communication channels with each receiver, whose type is common knowledge. In practice, early warning systems exists in areas prone to disasters such as floods, hurricanes or wildfires. Text messages or sirens can be triggered locally when a disaster occurs. Local news channels can be used to provide different pieces of information in different areas.

By allowing the sender to communicate privately with each receiver, we enlarge the set of communication strategies available to the sender. In particular, the posterior beliefs held by receivers after the communication phase need not be homogeneous, which implies that the response of the population may not be *monotonic* in type. Indeed, there might not exist a single cut-off $\theta^\star(r)$ separating the sets of responding and non-responding individuals. However, the following lemma states that we can restrict our analysis to monotonic communication strategies.

**Lemma 1.** *For any credible communication strategy, there exist a credible monotonic communication strategy that weakly increases expected welfare.*

*Proof.* A complete proof of this result is provided in the appendix. The economic intuition is the following. Given any communication strategy, if the profile of individual actions is not monotonic, then a permutation of the strategies used with the different receivers allows to reorder the set of responding agents in order to convince only the lowest types to respond to the disaster in the worst states of nature, without changing the sizes of the sets of responding and non-responding agents. This reordering mechanically improves expected welfare, by reducing the third term of equation (3), without affecting the first two. □

Hence, for any monotonic private communication strategy, welfare $W_{private}(r)$ can be calculated using equation (5). For all $r$, the first-best outcome of the game for the sender is to persuade all receivers whose type is below $r+\gamma$ to respond to the disaster. As a consequence, for any $\theta$, the sender wants to persuade $\theta$ to choose action $a=1$ when $r>\theta-\gamma$ and to choose action $a=0$ otherwise.

The main difference with the previous section is that now the government can design different communication strategies for each receiver. In this context, and for any receiver, the sender can only adopt two credible strategies: a babbling strategy where a single message is sent to the receiver (independent of $r$), and a two-message strategy where the cut-off between both messages is necessarily $r_c(\theta)=\theta-\gamma$. Any two-message communication strategy using a different cut-off and inducing two different actions would not be credible, as the sender would have a clear incentive to deviate from it.[25]

The optimization problem faced by the sender is to choose, for all $\theta$, among these two strategies. The following proposition characterizes the only private communication strategy which is both credible and monotonic. The profile of individual actions resulting from this communication strategy is presented in figure 4.

**Proposition 1.** *When $|\gamma|\geq\frac{1}{2}$, the sender engages in a babbling communication strategy with all receivers. When $|\gamma|<\frac{1}{2}$, the government communicates with all receivers satisfying the*

[25] Any communication strategy with more than two messages would be equivalent to one of the strategies stated above, as the receivers only has two different actions in his decision set.

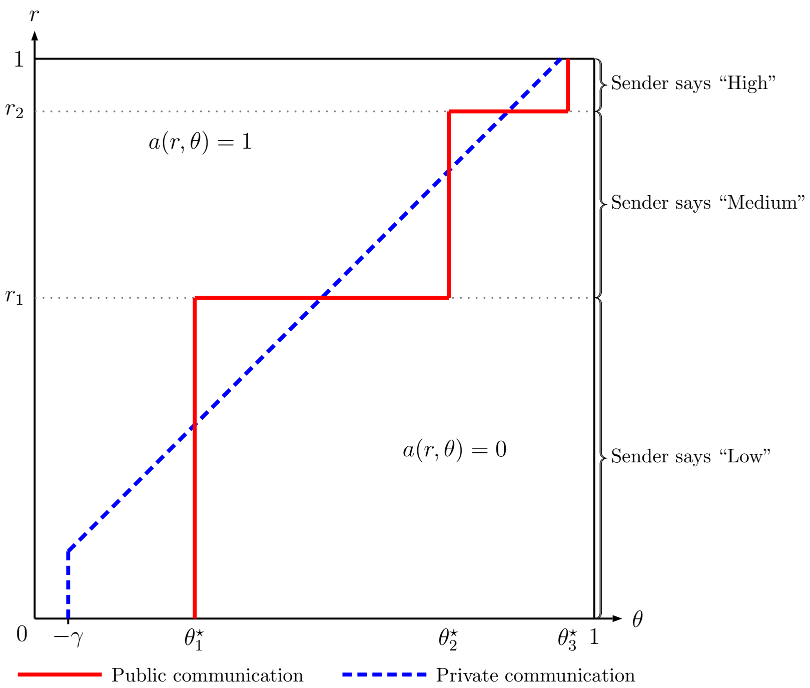


Figure 4: Comparison of the public and private most informative communication strategies when $\gamma = -0.06$)

*condition $\theta \in [|\gamma|; 1 - |\gamma|]$. The expected welfare from private communication is always weakly greater than the welfare obtained under public communication.*

The first part of Proposition 1 shows that some information can be communicated to vulnerable populations under private communication in a larger range of cases than under public communication. Last-mile communication hence improves the credibility of the sender, and her ability to disclose relevant information in equilibrium.

However, private communication changes the way the sender discloses information to the population. Figure 4 compares the profiles of actions obtained under both private and public communication. Whereas the informed party resorts to the use of severity scales in public, private communication amounts to issuing tailored recommendations to some individuals. More specifically, the sender uses private communication to persuade all receivers characterized by $\theta \in [|\gamma|; 1 - |\gamma|]$ to take her preferred action, and leaves all other receivers without information.

Receivers located in the extremities of the unit interval do not receive informative messages from the sender, as they cannot be convince or do not need to be. Under negative externalities - the case represented on figure 4 - receivers characterized by $\theta < -\gamma$ are too hard to convince due to their high ability to avoid harm. In equilibrium, they all take the protective action, regardless of the information communicated. Conversely, providing no information to receivers of types $\theta > 1 + \gamma$ leads them into choosing action 0, which is the preferred action of the sender in all states of the world.

In the case of positive externalities, the interpretation of the motivations of leaving some receivers with no information are interchanged. Receivers with a low private cost of avoiding harm need no information to always take the sender's preferred action. Conversely, receivers characterized by a high cost of protection are too hard to persuade. These receivers always fail to adopt the socially beneficial course of action.

The second part of Proposition 1 shows that private communication does not only extend the ability of the government to communicate, but also improves expected welfare. When the government can do better than the babbling equilibrium, and when $\gamma \neq 0$, private communication strictly improves expected welfare. This result is illustrated on figure 5: the distribution of individual actions is closer to the first-best solution under private communication than under public communication.

It also appears that for small values of $|\gamma|$, private (non-committed) communication performs better than committed full revelation of information, which itself dominates public non-committed communication. This result suggests that fostering *last-mile communication* between authorities and affected populations is a sound objective in the mitigation of natural catastrophes, as private communication improves transparency as well as the response of exposed populations. In this regard, our result is in line with the recommendation of the crisis management literature.

Proposition 1 differs from the classical multiple audience literature (see e.g. Farrell and Gibbons (1989), Goltsman and Pavlov (2011) or Battaglini and Makarov (2014) for experimental evidence), in which private communication is sufficient to ensure the existence of public communication. The insight usually put forward is one of mutual discipline, whereby communicating with two heterogeneous receivers curbs the incentives to lie of the sender, thereby improving communication. In our setting, on the contrary, public communication implies the possibility of private communication: there is mutual subversion. This converse result holds because our model features an heterogeneous audience characterized by a 'bias' $\gamma$, constant across receivers. Conversely, the literature on public/private cheap-talk usually assumes that receivers differ in their biases with the informed party but are otherwise identical.

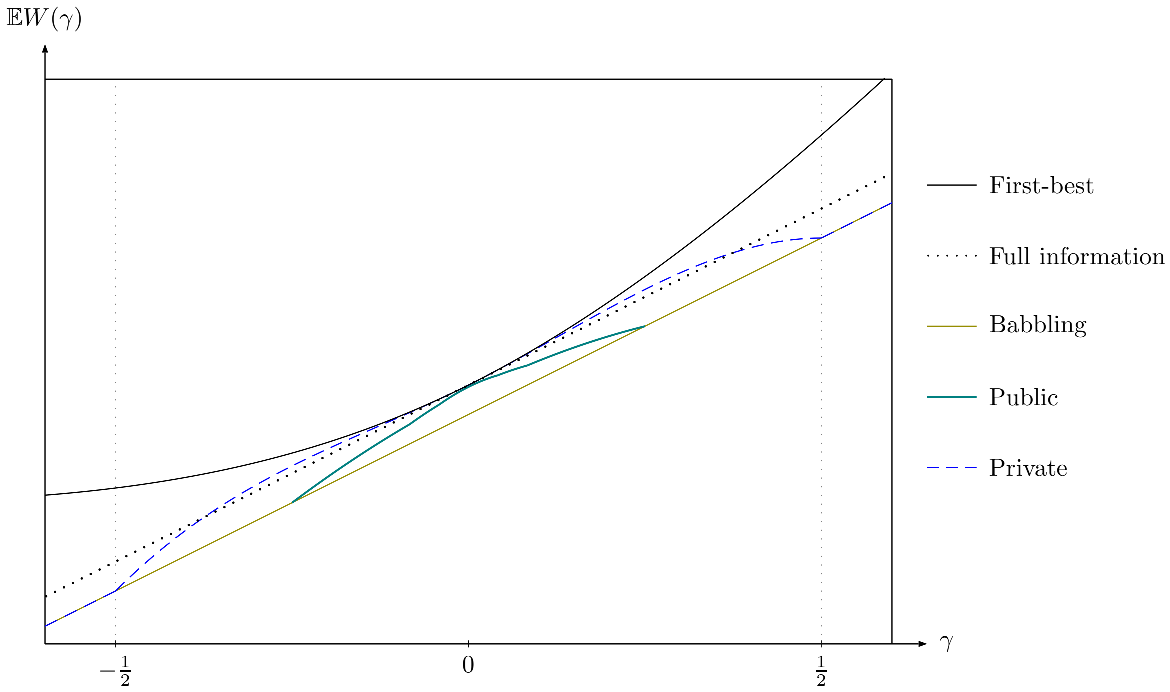


Figure 5: Expected welfare associated with different modes of communication

### 4.2 The value of commitment

The game presented above shows that, when individual and social preferences are not aligned, informed policy makers will find it optimal to distort the information disclosed to exposed populations. This efficiency-transparency trade-off arises from the lack of commitment of the informed parties. We believe this accurately describes many examples of crisis communication strategies, as well as some of their shortcomings.

On the contrary, the crisis communication literature advocates for commitment by governments to communicate truthfully and transparently during crises. This section challenges this recommendation by introducing commitment in the model. Doing so confirms the general intuition that committed communication improves welfare. However, we also demonstrate that truthful communication (i.e. full revelation) is not necessarily the optimal committed communication strategy.

Specifically, in the public communication game, commitment allows the full revelation of information, which increases welfare. However, optimal committed communication strategies always feature some level of pooling. Under negative externalities, the optimal strategy is transparent above some threshold, under which the information is pooled. By doing so, the informed party can always persuade some individuals with the smallest costs of response by restricting the information relative to the most benign states of the world.

Under commitment and private communication, the sender can persuade a larger proportion of the population to adapt their actions, but the optimal communication strategy is never truthful.

#### 4.2.1 Committed public communication

**Proposition 2.**

**Corollary 3.** *The optimal public committed communication strategy is fully revealing above or below some threshold depending on the sign of* $\gamma$*.*

#### 4.2.2 Committed private communication

In the committed private communication game, the sender can commit to a different revelation strategy with every single receiver. Contrarily to the cases described above, under this scenario the sender can always do better than babbling, regardless of the extent of the externalities associated with private responses. In other words, commitment in private can always be used to persuade some individuals to take more socially-optimal actions.

For instance, under negative externalities and without commitment, individuals characterized by the smallest cost of response could not be persuaded not to react to the incoming crisis under no commitment from the sender. These individuals were thus left without any relevant information, and thus always chose to respond to the crisis. Under commitment, more information can be disclosed to these individuals, which can in turn adapt their responses. This improves the population's aggregate response, and increases welfare. However, private committed communication is never truthful.

The proposition below summarizes these intuitions.

**Proposition 3.** *Commitment in private improves welfare, and the optimal private communication strategy under commitment differs from the private optimal non-committed communication strategy on the interval* $[0; \min(-\gamma, \frac{1}{2})]$ *if* $\gamma < 0$*, or* $[\max(1-\gamma, \frac{1}{2})]$ *if* $\gamma > 0$*.*

## 5 Global disaster management strategies: some coordination issues

A central issue in the management of major disasters is the response adopted by exposed populations. As we have described so far, this response can be influenced by the information disclosed by informed authorities. But other measures, such as preparedness or emergency response plans, can also shape the response of populations to these extreme events. The allocation of public resources to these actions is another salient aspect of disaster management strategies. In particular, preparedness and emergency response plans shift individual incentives and in turn affect the recommendations issued by authorities. The aim of this section is to analyze the coordination of these actions with the communication of disastrous events. To do so, we first study the case of public actions taken before the communication stage, and then turn to the case of public actions taken ex post.

### 5.1 The coordination of disaster communication with ex ante preparedness

We first focus on the the actions a government may take ex ante to mitigate catastrophes. In particular, preparedness is usually defined as the action of getting a population prepared to the possibility of catastrophic events by fostering the adoption of good courses of actions. Preparedness actions can consist, for instance, in exercise drills, adapted training, or in the communication of good practices. For instance, Pljansek et al. (2017) describe a case of preparedness measures taken in the island-city of Dordrecht in the Netherlands. During severe floods, only 10 to 20% of the population can be safely evacuated from the city before the water levies fail. Hence, to avoid potential casualties associated with an evacuation congestion and the failures of water levies, recent preparedness programs aimed to convince people to respond to flood alerts by taking shelter on their roofs or in elevated public shelters.

Preparedness programs aim to limit the negative external effect of the actions taken by individuals in response to an incoming disaster, or to increase their pro-social consequences. We model these programs as ex-ante modifications of the parameter $\gamma$ characterizing the external effects of individual responses, and consider an extension of our cheap-talk game, in which the sender can choose ex ante (before observing $r$) the extent of the externalities $\gamma$. First, let the sender choose $\gamma$ at no cost in the positive unit interval (a symmetric case using the negative unit interval is also discussed).[26] This simple refinement of the game leads to the following straightforward result.

**Corollary 4.** *When the sender can choose $\gamma$ at no cost in $[0;1]$, the highest level of expected-welfare is obtained when choosing $\gamma = 1$. When $\gamma$ can be chosen at no cost in $[-1;0]$, the highest*

[26] Not allowing the sender to choose $\gamma$ over $[-1;1]$ implicitly assumes that the sender cannot change the nature of an external effect, but only influence its size through preparedness. This assumption is required to illustrate the different incentives at play under positive and negative externalities, which respectively lead the sender to choose the maximum and minimum bias.

*level of expected-welfare is obtained when choosing* $\gamma = 0$.

Under negative externalities, corollary 3 shows that the outcome of the extended game is full communication as the preferences of individuals and the government are perfectly aligned. In this case, there is no trade-off between transparency and social welfare. This is the case described in the flood example presented above. When too many people try to evacuate by land, congestion slows down the evacuation, endangers the population, and limits the credibility of the public authority ex interim. Convincing people ex ante to take shelter on their roofs reduces the ex post harm due to the external effects of individual responses, and reduces the incentives for the government to manipulate the information disclosed in equilibrium.

Under positive external effects, when the sender is constrained to choose the external effect of the receivers' actions within $[0; 1]$, she will choose $\gamma = 1$. In this case, the equilibrium played is the babbling equilibrium. Here, allowing individuals to have strong pro-social behaviors completely offsets the cost of the catastrophe. In particular, society strictly benefits from any receiver taking the costly action. An example of this result is the management of epidemics or contaminated food stocks. In these situations, it is unlikely to see the government trade-off public health with the ability to communicate, and one could expect the government to require mandatory vaccinations or the destruction of entire food stocks, hence adopting an uninformative communication strategy.

We now assume that $\gamma$ can be shifted from an initial value $\gamma_0$ and at some cost over the whole $[-1; 1]$ interval. The game takes place as follows: the (deep-pocket) sender first learns the external effect of individual actions $\gamma_0 \in [-1; 1]$, and may invest in order to shift $\gamma_0$. The resulting level of externalities $\gamma$ is then observable by the receivers. Once the investment is realized, the cheap-talk game is played as before. We assume that the investment required to shift $\gamma_0$ is increasing and convex in the width of the shift: the cost function $\psi(|\gamma - \gamma_0|)$ is assumed to be increasing and convex in its argument.

As the first step of this new game carries no information regarding the state of the world, the cheap-talk game is played as before, under externalities $\gamma$ resulting from the investment of the sender. This new game can thus be solved by backward induction. Let $\mathbb{E}W_{\text{prep}}(\gamma)$ denote the expected welfare of this new game. Then, we have:

**Corollary 5.** $\mathbb{E}W_{prep}(\gamma)$ *can admit multiple global optima, which are all weakly inferior to* $\gamma_0$.

Hence, either $\mathbb{E}W_{\text{prep}}(\gamma)$ has a single global maximizer (for instance, this is the case if $\mathbb{E}W_{\text{prep}}(\gamma)$ is quasi-concave), or it has several of them. In the first case, we note the global maximum $\gamma_{max}$. As $\psi$ is convex and positive, $\gamma_{max}$ is necessarily weakly superior to $\gamma_0$. Intuitively, the sender always has an incentive to reduce the extent of the external effects of the receivers' actions.

In the second case, we note $\Gamma = \text{argmax}_\gamma\{\mathbb{E}W_{\text{prep}}(\gamma)\}$. $\Gamma$ contains at least two elements. Although these elements cannot be distinguished using this ex ante welfare criterion, these values of $\gamma$ entail different outcomes, which trade-off the expected welfare resulting from the cheap-talk game with the cost of preparedness actions, and differ in the amount of information disclosed by the sender in equilibrium.

Choosing among these optimal solutions requires to select among their different properties. In particular, if there are multiple solutions, some entail more information transmission in equilibrium than others. The element of $\Gamma$ characterized by the lowest absolute value (i.e. $\text{argmin}_{\gamma\in\Gamma}\{|\gamma|\}$) is the solution that leads the informed party to communicate in the most informative way in equilibrium. Two other elements of $\Gamma$ have particular properties: the largest element of $\Gamma$ corresponds to the smallest amount of investment ex ante. A budget-constrained sender may opt for this solution. On the contrary, the smallest element of $\Gamma$ corresponds to the largest amount of investment required ex ante, but also yields the largest expected welfare from the cheap-talk game.

This extension shows that preparedness programs aiming to reduce the external effects associated with protective actions interact with the communication game. In particular, fostering pro social responses does not necessarily increase the ability of informed parties to communicate with exposed populations, as it may increase the incentives of the informed party to withhold information.

## 5.2 The coordination of disaster communication with ex post transfers

We now turn to the question of how ex post transfers interact with the communication stage and affect the response of exposed populations. Numerous examples of both monetary and non-monetary ex post transfers occur in the wake of major disasters. Disaster relief funds can be used to compensate victims, and emergency response plans dedicate human resources - such as military forces or fire-fighters - to the rescue of victims.

The coordination of these two dimensions - communication and ex post actions - is paramount in the management of major crises, as they both determine how a society responds to catastrophes. Here, we suppose that the sender can perform positive transfers subject to a budget constraint. We assume that the government can spend up to $B$ to compensate the population, where $B < |\gamma|$, so that solutions are necessarily second-best.[27]

#### 5.2.1 Partial public insurance and subsidies

In a first benchmark case, we assume that the sender commits to transferring non-negative amounts $t_0$ and $t_1$ to all receivers engaged respectively in action $a = 0$ and $a = 1$, regardless of the state $r$. We note $\Delta t = t_1 - t_0$, and assume that the sender's budget is constrained by a positive quantity $B$ such that:

$$\forall r, \int_{\Theta_1(r)} t_1 d\theta + \int_{\Theta_0(r)} t_0 d\theta \leq B < |\gamma|. \tag{18}$$

We assume that individual utilities are linearly affected by these transfers:

$$u_R(r, \theta, a) = \begin{cases} -r + t_0 + \gamma\bar{a}(r) & \text{if } a = 0 \\ -\theta + t_1 + \gamma\bar{a}(r) & \text{if } a = 1 \end{cases} \tag{19}$$

A receiver now chooses action $a = 0$ if and only if $\theta > \mathbb{E}(r) + \Delta t$. This does not affect the structure of equilibria, and proposition 0 still holds. Though, transfers affect the Bayesian rationality constraint of the receivers. Conditionally on a credible message sent in equilibrium on any interval $[r_a; r_b]$, the equilibrium outcome function $\theta^\star(r)$ now has to satisfy:

$$\theta^\star = \frac{r_a + r_b}{2} + \Delta t. \tag{20}$$

As a consequence, equation (8) now yields:

$$r_{i+1} - r_i = r_i - r_{i-1} + 4(\gamma - \Delta t). \tag{21}$$

Equation (21) shows that after choosing a transfer program $(t_0; t_1)$, the subsequent cheap-talk game is characterized by the same communication equilibria as the original cheap-talk game under external effects $\gamma' = \gamma - \Delta t$. In other words, transfers allow the sender to access different communication equilibria. Intuitively, when $\Delta t$ and $\gamma$ have the same sign, transfers compensate the external effects, and the sender will access more informative credible communication strategies. When $\Delta t$ and $\gamma$ have opposite signs, transfers accentuate the external effects, and credible communication strategies become less informative. The following proposition characterizes op-

[27] For instance, in the case of negative externalities, the sender could transfer $|\gamma|$ to all receivers choosing $a = 0$, which would perfectly align the incentives of the sender with those of the receivers.

timal transfers.

**Proposition 4.** *Under negative externalities, optimal transfers entail a partial public insurance for harmed receivers, i.e.* $t_0 > 0$ *and* $t_1 = 0$*. Under positive externalities, optimal transfers entail a subsidy for the costly protective action, i.e.* $t_0 = 0$ *and* $t_1 > 0$*.*

Proposition 3 has straightforward policy implications. The informed party should provide subsidies for actions characterized by positive externalities, and partial public insurance to individuals who cannot protect themselves when actions are characterized by negative externalities. These transfers increase welfare by improving the quantity of information disclosed by the informed party in equilibrium.

This result needs not be interpreted in pure monetary terms. Indeed, transfers can also be in-kind or take the form of emergency response plans. In this sense, our result suggests that emergency resources should either target responding populations when response has pro-social consequences (e.g. concentrate public expenditure on the support of quarantined populations after the outbreak of an epidemic, or on the reduction of vaccination costs), and target victims when response has negative external effects (e.g. deploy military forces in flooded areas to help those who did not or could not evacuate).

Another key contribution of this result pertains to the Samaritan dilemma. Proposition 3 provides a rationale for the commitment problem faced by public authorities when facing the risks of rare disasters such as floods. In the long run, the existing literature has argued that providing insurance to at-risk populations leads to moral hazard, as ex post public insurance fails to provide incentives for individuals to exert optimal levels of protective efforts ex ante (see e.g. Kunreuther, 1996). In the short run however, our model shows that the government will find it optimal to provide relief to at-risk populations, as it enables a better crisis management and leads to a better response. Hence, if the public authority is short-sighted, or if the short-term gains associated with these transfers outweigh the long-term costs of moral hazard, then the public authority will not be able to commit ex ante not to provide insurance to populations at risk.

The proof of proposition 3 also shows that optimal transfers are non-decreasing in $B$, but less than proportional to it. As a consequence, the marginal welfare gains associated with an increase of the size of the relief fund are decreasing. This is so because increasing the budget constraint increases both the intensive and extensive margins of transfers. Indeed, when $B$ increases, the quantity of receivers demanding these transfers in equilibrium also increases. In the case of positive externalities, an increase in the budget leads the subsidy $t_1$ to be provided to more numerous receivers when $r$ is large. In the case of negative externalities, an increase in the budget would lead the partial public insurance $t_0$ to be provided to more numerous receivers when $r$ is low.

#### 5.2.2 On the use of disaster relief funds

This analysis constitutes a benchmark that stands on the strong assumption that transfers are committed: in any state of the world $r$, the informed party has to stick to the program $(t_0; t_1)$ that has been defined in proposition 3. This commitment can be defended in the case of non-monetary transfers - such as emergency response plans - which are designed ex ante and supposed to be executed in the wake of the catastrophe, and somehow regardless of the specifics of the catastrophic event at play.

However, commitment may be less compelling when transfers are used to model disaster relief funds. Indeed, in this case, proposition 3 implies a counter-intuitive result regarding the timing of the depletion of the government's budget: in the case of negative externalities, the budget is completely depleted only if $r$ is below $r_1$, i.e. when the least severe catastrophes occur. This result is due to the fact that a single transfer program $(t_0; t_1)$ had to satisfy the sender's budget constraint in all states of nature. Yet, a policy-maker may want to withhold the use of a relief fund in order to save it for very severe events. For instance, in the United-States, the assistance resources gathered by FEMA require several conditions before being allocated to any harmful event. In particular, FEMA disaster declarations can be motivated by damage assessments conducted by affected communities.[28]

Hence, it is interesting to study the case in which the pair $(t_0; t_1)$ may depend on the state of nature, thus relaxing the sender's budget constraint. In the most general case, the Bayesian rationality constraint of the receivers takes a more complex form:

$$a = 0 \Leftrightarrow \theta > \mathbb{E}(r + \Delta t(r)|m(r)) \tag{22}$$

Then, defining $\mathbb{E}_i(\Delta t) \equiv \mathbb{E}(\Delta t(r)|r \in [r_{i-1}; r_i])$, equation (22) yields the following induction condition on the structure of equilibria:

$$\forall i < n, \ r_{i+1} - r_i = r_i - r_{i-1} - 4\gamma - 2\left[\mathbb{E}_i(\Delta t) + \mathbb{E}_{i+1}(\Delta t)\right]. \tag{23}$$

[28] See e.g. https://www.fema.gov/disaster-declaration-process for further details on the disaster declaration process adopted by FEMA.

Characterizing closed form solutions of partition equilibria satisfying equation (23) is beyond the scope of this paper. To overcome this tractability issue, we propose to study a simple policy instrument that illustrates the *state of natural catastrophe* (an instance of a state of emergency), which determines in numerous countries when public funds can be used to compensate the victims of a disaster. To do so, instead of conditioning transfers on states of the world, we restrict the analysis to the case of constant transfers that can only be made if a catastrophe exceeds a certain threshold.

Suppose that a government has access to a relief fund $B$, and can determine a threshold $r_{cat}$ above which this budget will be used in order to compensate victims. When $r < r_{cat}$ the utility of a receiver is given by equation (1). When $r > r_{cat}$, their utility is described by equation (19). The threshold $r_{cat}$ serves both as a trigger for the relief fund, and as a communication device to warn the population. In equilibrium, the definition of this threshold needs to be credible for the population. Hence, we necessarily have:

$$W(r_0, \theta_1^\star) = W(r_0, \theta_2^\star), \tag{24}$$

where $\theta_1^\star$ and $\theta_2^\star$ describe the actions played in equilibrium when $r$ is respectively below and above $r_{cat}$. The Bayesian rationality constraints imply that $\theta_1^\star = \frac{r_{cat}}{2}$ and that $\theta_2^\star = \frac{1+r_{cat}}{2} + \Delta t$. Finally, the budget constraint of the sender reads:

$$\int_0^{\theta_2^\star} t_1 d\theta + \int_{\theta_2^\star}^1 t_0 \leq B. \tag{25}$$

This can easily be shown to be equivalent to $(\Delta t)^2 + \frac{1+r_{cat}}{2}\Delta t + t_0 \leq B$.

**Corollary 6.** *For any transfers $t_0$ and $t_1$, there is a unique credible equilibrium characterized by a single threshold $r_{cat}$:*

$$r_{cat} = \Delta t + 2\gamma + \frac{1}{2} \tag{26}$$

*In addition, when $\gamma > 0$, equilibrium transfers consist in partial public insurance granted when $r > r_{cat}$ to receivers who choose action $a = 0$.*

We next turn to the determination of the transfers made in equilibrium. Using the definition of the expected welfare and the budget constraint, the optimization problem can be shown to boil down to:

$$\max_{t_0} -\frac{t_0^3}{2} + (2\gamma - \frac{3}{8})t_0^2 - \gamma(2\gamma - 1)t_0 \tag{27}$$

$$\text{s.t. } \frac{3}{2}t_0^2 + (\frac{1}{4} - \gamma)t_0 - B \leq 0 \tag{28}$$

Then, the following result holds:

**Corollary 7.** *If the budget of the sender is large enough, it is not necessarily depleted in equilibrium.*

This result is intuitive: if the budget is too small, the sender increases the size of transfers in order to improve welfare until the budget constraint is binding. If the budget $B$ is large enough, the sender can maximize expected welfare without depleting the whole fund.

The study of this simple policy instrument shows that it is possible to combine communication with the use of relief funds in order to convey credible information to the population, and to foster socially optimal responses to catastrophic events. In addition, the use of thresholds to trigger the use of relief funds can be a useful instrument to avoid squandering resources during minor events. In this sense, it appears that using simple instruments such as a pre-determined *state of natural catastrophe* is a sensible policy.

This result still holds if we assume that the relief fund has to be depleted, i.e. if equation (28) has to be binding. This assumption is consistent, for instance, with the case of a populist sender searching to buy votes by distributing the totality of the relief fund in the wake of a major disaster.

Under this assumption, the solution provided above is still optimal up to a symmetric increase of both types of transfers. Indeed, the solution can first be characterized by a binding budget constraint, in which case this is an optimal solution transfer for the politician. In the other case, the politician can shift the optimal $t_0$ found above as well as the transfer $t_1$ made to receivers engaging in the protective action. Because expected welfare only depends on the difference between the two transfers, a parallel shift of $t_0$ and $t_1$ allows the politician to deplete the whole fund, without hindering the effect of these transfers on the incentives of the population to take protective actions.

# 6 Alternative specifications and interpretations of individual preferences

## 6.1 *Better safe than sorry*: the political economy of snowstorm communication

Snowstorms are another case of major events that require informed authorities to communicate with exposed populations about incoming hazards. The observation of past snowstorm cases shows that city officials tend to overreact to incoming snowstorms, shutting-down public transportation in entire cities and recommending populations to stay home, even when temperatures and snowfalls do not exceed particularly extreme thresholds.

These (over)-reactions have been rationalized by policy-makers by prudence, or by some form of a precautionary principle, invoking the *better safe than sorry* adage to justify apparently excessive public expenditures and the inconveniences caused to local citizens by the shut-down of public services.

According to our model, pooling extreme snowstorms with milder ones is consistent with the equilibrium strategies adopted under positive externalities associated with protective actions. Though, the existence of positive externalities associated with staying home during a mild snowfall does not appear as a compelling story. However, an alternative specification of individual preferences can be used to provide a more compelling explanation of observed snowstorm communication policies.

Assume now that $\gamma\bar{a}$ in equation (1) captures a cost proportional to the size of the population which chose action $a = 0$, i.e. $\bar{a}(r) = \int_0^1 1 - a(r, \theta)d\theta$. This alternative specification can be interpreted as a political cost associated with a change in the opinion of the population. After a disaster, the media may relate the stories of those who were not advised to seek protection from the disaster. In the case of snowstorms, black ice may cause injuries due to pedestrian falls or accidents associated with people losing the control of their vehicles.

The publicity associated with the existence of these victims may in turn sway the population into accusing its policy maker of negligence, and cost her future votes or intensified political opposition. A city official may for instance fear that individuals who haven't received such a recommendation would hold him or her responsible for it, and wouldn't vote for his re-election. Public accusations of negligence can also lead the politician to a forced resignation. In this set-up, $\gamma$ would represent the propensity of the opinion to be swayed by the existence of these victims, or the ability of the media to gather information and communicate about them.

This alternative specification does not alter the result of our study beyond the interpretation of the conflict of interest arising from the aggregation of individual preferences. The necessary condition for the existence of a partitioning equilibrium is now obtained by changing the sign of $\gamma$ in equation (12):

$$r_{i+1} - r_i = r_i - r_{i-1} - 4\gamma. \tag{29}$$

One would expect a policy-maker wary of the political consequences of her own attitude towards catastrophic hazards to engage in "pooling at the top": the political costs incurred by the policy-maker when an individual chooses not to seek shelter leads the informed party to choose communication strategies were communication pools together the most severe events. In addition, the larger the extent of the political cost $\gamma$, the more uninformative will be the reaction of the politician to the incoming snow storm. In the limit case where $\gamma < -1/4$, all snowfalls are met with an equal intensity.

In addition, snowstorms are usually met with temporary school closures and public transportation shutdowns. These actions can be analyzed using the extension of our model where ex post transfers are allowed. In this extension, when using the alternative definition of $\bar{a}$, condition (21) yields $r_{i+1} - r_i = r_i - r_{i-1} - 4(\gamma + \Delta t)$, and optimal transfers entail $\Delta t > 0$ when $\gamma < 0$, as the policy-maker seeks to incentivize individuals to adopt action 1 (e.g. *stay home*) when she faces a cost associated with action 0 (e.g. *go to work despite the snow*). In this sense, shutting down public services during snowstorms deters people from leaving the safety of their homes, either because schools cannot take care of their children, or because public transportation systems are not available, or because the city decided to let the snow accrue in the streets.[29]

### 6.2 Alternative micro-foundations

The preferences presented in equation 1 provide a simple alternative micro-foundation for the quadratic utilities at the core of most cheap-talk games. In our set-up, contrarily to most games of expertise communication (see e.g. Krishna and Morgan, 2001, 2004), the divergence between private and social objectives arise endogenously, from the aggregation of individual preferences. Yet, the conclusions we drew so far are determined by the existence of an external effect borne by all individuals when some receivers take the protective action $a = 1$.

However, in many situations, the adverse effects of seeking protection are only borne by a specific share of the population. Two cases illustrate this in a clear manner. First, in the case

[29] Note however that although these in-kind transfers are consistent with a positive $\Delta t$, they rather embody a negative $t_0$ (e.g. a disincentive to deviate from action 1) than a positive $t_1$.

of hurricanes or nuclear accidents, congestion externalities are (mostly) borne by the population stuck on highways and exposed to winds or to a radioactive fallout. Second, in the case of vaccines, herd immunity reduces the pool of individuals who may carry some disease, and benefits the group of individuals that did not - or could not - take the vaccine. Therefore, we propose two alternative model specifications, where the adverse effects of taking or not taking the protective action yields some consequences on only one part of the population.

First, we consider a *congestion game*, where the congestion externality is only borne by responding individuals. Hence, the social cost of taking action $a = 1$ is still described as $\gamma \int_0^1 a(r,\theta)d\theta$, but this cost is only borne if an individual chooses $a = 1$. Hence, we have:

$$u_R(a,\theta,r) = \begin{cases} -r, & \text{if } a = 0 \\ -\theta + \gamma \int_0^1 a(r,\theta)d\theta, & \text{if } a = 1 \end{cases} \tag{30}$$

Next, we consider a *vaccination game*, where herd immunity is described as a positive effect proportional to the share of people taking action $a = 1$. However, we assume that this positive effect is borne only by the population of individuals choosing $a = 0$. Hence:

$$u_R(a,\theta,r) = \begin{cases} -r + \gamma \int_0^1 a(r,\theta)d\theta, & \text{if } a = 0 \\ -\theta, & \text{if } a = 1 \end{cases} \tag{31}$$

Note that the two examples above could be declined in six additional variations in order to capture any hypothetical case where one action affects one of the two groups.

We here focus on the congestion game described by equation (30). Under public communication, the Bayesian rationality constraint of the receivers leads to a profile of individual actions described by $\theta^\star(r) = \frac{\mathbb{E}(r)}{1-\gamma}$. The welfare in state $r$ is given by $W(r) = -r(1-\theta^\star) + (\gamma - \frac{1}{2})\theta^{\star 2}$. Corollary 1 still holds, so there is no loss of generality to look for partition equilibria of the usual form. In this case, the sender's incentive compatibility constraint associated with any partition equilibrium yields $r_{i+1} = \frac{2}{1-2\gamma} r_i - r_{i-1}$.

Similar equilibria have been described in Antic and Persico (2016), albeit in a quite different setting. We do not reproduce their proofs here. Cut-off states $(r_i)$ and equilibrium outcomes $(\theta_i^\star)$ admit closed-form solutions that involve the Chebyshev polynomials of the second-kind. When $\gamma < 0$ (i.e. in the case of a negative congestion effect), an equilibrium constituted of $n$ partitions exists if and only if $0 > \gamma > \frac{1}{2}(1 - \frac{1}{cos(\frac{\pi}{2n})})$. The main properties of these equilibria are similar to the usual linear-quadratic case: expected welfare is increasing in the number of partitions, which are characterized by decreasing widths. In other words, expected welfare increases with transparency, while credibility requires the policy maker to disclose more information when the severity of the incoming event increases. In summary, under public communication, our results are qualitatively robust to this alternative specification.[30]

### 6.3 Heterogeneous risk perceptions

Our results are robust to an alternative specification, where the bias between the sender and the receivers is no longer additive, but multiplicative. A simple way to illustrate this case is to consider the following representation of individual preferences:

$$u_R(a,\theta,r) = \begin{cases} -\gamma r, & \text{if } a = 0 \\ -\theta, & \text{if } a = 1 \end{cases} \qquad u_S(a,\theta,r) = \begin{cases} -r, & \text{if } a = 0 \\ -\theta, & \text{if } a = 1 \end{cases} \tag{32}$$

Under this new specification, $u_S$ characterizes the preferences of the sender regarding the decisions made by each receiver. Welfare is then defined as the aggregation of $u_S$ across receivers. Using these alternative preferences, it can be shown that the main properties of the cheap-talk equilibria are preserved (see e.g. Antic and Persico, 2016). In particular, the interval structure of communication equilibria, and their welfare properties, still hold. More precisely, when $\gamma < 2$, the Bayesian rationality constraint yields $a = 0 \Leftrightarrow \theta_i > \gamma \frac{r_i + r_{i-1}}{2}$, and the incentive compatibility constraint yields $r_{i+1} = 2\beta r_i - r_{i-1}$ with $\beta = (\frac{2}{\gamma} - 1)$. Partition equilibria of up to $n$ messages can be shown to exist whenever $\beta > \cos(\frac{\pi}{2n})$. Any equilibrium featuring $n$ messages are then defined by cut-off states $r_0 = 0$, $r_1 = \frac{1}{U_{n-1}(\beta)}$ and $r_i = U_{i-1}(\beta) r_1$, where $U_i$ denotes the i-th Chebyshev polynomial of the second kind.

This alternative specification is interesting as it allows a new interpretation of the source of friction $\gamma$. In particular, $\gamma$ can capture the existence of a systematic underestimation or overestimation by the receivers of the damage associated with the disaster. This echoes the premises of the Happyville literature (see Portney, 1992; Salanié and Treich, 2009), in which a regulator and a population have heterogeneous perceptions of the risks they face. In this sense, our results can be interpreted as an extension of this literature to the study of communication under heterogeneous risk perceptions.

[30] When $\gamma$ is positive, the game no longer matches the congestion case, as a positive $\gamma$ implies that individual responses entail positive effects on the responding population. However, a novelty associated with this variation of the model is that communication can be based on an arbitrarily large number of partitions. Nevertheless, Antic and Persico (2016) show that the informativeness of the communication remains bounded in equilibrium as the width of the topmost partition is bounded when the number of partition increases.

This interpretation of our results is consistent with the analysis of Hasegawa (2013), who stresses the role of risk perceptions in the responses of local populations during the Fukushima-Daiichi accident. For instance, $\gamma > 1$ in equation (32) would embody the assumption that populations systematically overestimate the potential damage due to the incoming disaster. In this case, the model yields the same results as in the original case of negative externalities. Credible communication strategies entail a finite number of messages, that are more precise when disastrous events are more severe. In particular, sufficiently large discrepancies in risk perceptions could explain the silence of the Japanese government in the days that followed the nuclear accident, and the following distrust of the Japanese population towards the recommendations issued by their government.

# 7 Conclusion

Even a benevolent government faces credibility issues when communicating about major disasters with an exposed population. We study these situations by presenting a model of strategic communication between a sender informed of an incoming catastrophe and a continuum of receivers characterized by heterogeneous abilities to avoid harm. Receivers take binary protective actions which entail an external cost for society, and the informed party tries to persuade them to act in a way that minimizes the social cost of the event. Our model confirms some of the recommendations of the disaster management literature and provides new insights into how credible communication strategies can be designed to better respond to natural catastrophes or rare technological disasters.

The model first shows that effective communication is equivalent to providing recommendations regarding optimal actions. In this sense, providing large quantities of information in the wake of a disaster may not help public authorities restore their credibility. On the contrary, the model suggests that simply providing instructions for the population to follow may be a more sensible policy.

In addition, the model rationalizes the value of transparency in public communication. Although it is clear that informed parties have an interest in withholding some information to improve the response of exposed populations, the effective management of major disasters requires them to disclose as much information as possible. As a corollary, restoring private communication with each affected community appears as a key to increasing the transparency of disaster communication and to improving a society's response to a disaster.

We also stress the need to design communication strategies not only based on the severity of the event considered, but also based on the type of individual responses that should be discouraged or fostered. In particular, deterring costly social actions requires to disclose more information regarding severe events, while pro social actions can be encouraged by pooling together the most critical events. This result rationalizes the use of *better-safe-than-sorry* policies: pooling together the most critical events can incentivize exposed populations to adopt pro-social behaviors.

The analysis also sheds light on the need to coordinate disaster communication with ex ante and ex post actions taken to improve the response of society to extreme events, as these actions affect the ability of public authorities to transmit information during the communication stage. In particular, although preparedness always increases welfare, it can also increase the conflict of interest of the informed party, and hence conflict with transparency.

Finally, when the informed party can use transfers to offset the bias of the population, we show that an optimal policy is to subsidize costly actions when these actions entail positive externalities, and to provide partial public insurance when protective actions entail negative externalities. In addition to being a first analysis of the interaction of committed transfers with the equilibria of a cheap-talk game, this final finding provides a rationale for the central commitment issue leading to the Samaritan dilemma.

## A Proofs

*Proof.* Proof of Lemma 0 When $\gamma \leq 0$, the first-best response is obtained when $\theta^\star = 0$ if $r \leq -\gamma$ and $\theta^\star = r + \gamma$ otherwise. When $\gamma \geq 0$, the first-best response is obtained when $\theta^\star = 1$ if $r \geq 1 - \gamma$ and $\theta^\star = r + \gamma$ otherwise. When receivers are fully informed, their privately optimal response is $\theta^\star(r) = r$. Combining these responses with equation (5) yields the result of the lemma. □

*Proof of Proposition 0.* In equilibrium, $\theta^\star$ is necessarily increasing in $r$. To see this, suppose there exist $\theta_1^\star$ and $\theta_2^\star$ induced in equilibrium such that $\theta_1^\star < \theta_2^\star$. Then, there exists $r$ such that S is indifferent between $\theta_1^\star$ and $\theta_2^\star$, and the function $W(r, \theta_1^\star) - W(r, \theta_2^\star)$ is decreasing in $r$. Therefore, for any $r_1$ and $r_2$ that respectively induce $\theta_1^\star$ and $\theta_2^\star$, we have $r_1 < r_2$.

Next, notice that as $\theta^\star$ is increasing, it has to be continuous and differentiable almost everywhere on $[0; 1]$. Then, suppose there exists a point $r_0$ at which $\theta^\star$ is differentiable and its derivative is not null. Then the belief held by all receivers upon reception of the message associated with this point is the singleton $\{r_0\}$, which implies that $\theta^\star(r_0) = r_0$. Then, if $\gamma > 0$, there exist $\epsilon > 0$ such that $\theta^\star(r_0 + \epsilon) \geq r_0$ and $r_0 + \epsilon - \gamma < r_0$. When $r = r_0 + \epsilon$, the sender has an incentive to deviate from $m(r_0 + \epsilon)$, as she is strictly better off when sending $m(r_0)$. If $\gamma < 0$, then there exist $\epsilon > 0$ such that $\theta^\star(r_0 - \epsilon) < r_0$ and $r_0 - \epsilon - \gamma > r_0$, and the sender has an incentive to send message $m(r_0)$ when $r = r - \epsilon$.

Hence, $\theta^\star$ is constant wherever it is continuous, which implies that equilibria involve at most a countable number of messages. Finally, all equilibrium outcomes induced in equilibrium have to be separated by at least $|\gamma|$, or they would otherwise violate the receivers' Bayesian rationality constraint. This yields that all equilibria involve finitely many action profiles each characterized by a $\theta_i^\star$. □

*Proof of Corollary 1.* If an equilibrium characterized by $n$ equilibrium outcomes exists, then $r_i = \frac{i}{n} - 2\gamma i(n - i)$ is a necessary condition implied by equation (12). This condition ensures the uniqueness of the equilibrium. In addition, the equilibrium exists if the sequence of thresholds defined above is increasing. When $\gamma < 0$ and $n \geq 2$, the sequence of thresholds is increasing if and only if $r_{n-1} < r_n = 1$. Likewise, for $\gamma > 0$ and $n \geq 2$, the sequence of thresholds is increasing if and only if $0 = r_0 < r_1$. These two conditions yield the result stated in the lemma. □

*Proof of Corollary 2.* To see the first part of the result, notice that $\forall i \in \mathbb{N}$, $\mathbb{E}W(i, \frac{1}{2i(i-1)}) = \mathbb{E}W(i - 1, \frac{1}{2i(i-1)})$, that $\mathbb{E}W(i, \frac{-1}{2i(i-1)}) = \mathbb{E}W(i - 1, \frac{-1}{2i(i-1)})$, and that $\mathbb{E}W(i, \gamma) - \mathbb{E}W(i - 1, \gamma)$ is a quadratic polynomial in $\gamma$, with negative first coefficient. Hence, when the equilibrium with $i$ messages exists, it dominates the equilibrium with $i-1$ messages. The same reasoning holds for the second part of the result. $\square$

*Proof.* Proof of lemma 1 Let $a_m(r,\theta)$ describe the profile of individual decisions resulting from an arbitrary communication strategy $m(r,\theta)$ chosen by the sender. For every $\theta$, a message resulting in $a(r,\theta)=1$ is referred to as $m_1$, and a message resulting in action 0 is noted $m_0$.

First, for any $\theta$, let $p(\theta)=\int_0^1 a(r,\theta)dr$ denote the size of the set of states over which this receiver takes action 1. Then, let $q(r)=\int_{1-p(\theta)}^1 a(r,\theta)d\theta$ denote the set of states larger than $1-p(\theta)$ where the receiver responds. If there exists $\theta$ such that $q(\theta)\neq p(\theta)$, then there exists two states $r_1$ and $r_2$ such that $r_1<1-p(\theta)<r_2$ and $a(r_1,\theta)=1$ and $a(r_2,\theta)=0$. Then, define a strategy $m'$ such that for all $(r,\theta)$ where $p(\theta)=q(\theta)$, $m'(r,\theta)=m(r,\theta)$, for all $(r,\theta)$ where $p(\theta)\neq q(\theta)$, $m'(r,\theta)=m_0'$ when $r<1-p(\theta)$ and $m'(r,\theta)=m_1'$ when $r\geq 1-p(\theta)$.

By construction, we have $\mathbb{E}(r\mid m_1')\geq \mathbb{E}(r\mid m_1)$ and $\mathbb{E}(r\mid m_0')\leq \mathbb{E}(r\mid m_0)$. Hence, for any communication strategy $m$, we can design a new communication strategy $m'$ for which there exist a threshold $r^\star(\theta)$ such that the resulting profile of action $a'(r,\theta)$ satisfies $a'(r,\theta)=1\Leftrightarrow r>r^\star(\theta)$.

Next, consider the communication strategy $m''$ defined as the non-decreasing reordering of $m'$. Formally, for all $\theta$, define $\tilde{\theta}=||\ \{\theta' : r^\star(\theta)<r^\star(\theta')\}\ ||$. Then, for all $r$, let $m''(r,\tilde{\theta})=m'(r,\theta)$.[31]

By construction, m" is monotonic. To see this, notice first that the profile of action $a''(r,\theta)$ resulting from $m''$ satisfies $a''(r,\tilde{\theta})=1\Leftrightarrow r>r^\star(\theta)$ by definition of $\tilde{\theta}$.[32] Next, if $m''$ is not monotonic, then there must exist $r$, $\theta_1$ and $theta_2$ such that $\tilde{\theta_1}<\tilde{\theta_2}$ while $r^\star(\theta_1)>r>r^\star(\theta_2)$, which clearly contradicts the definition of $\tilde{\theta_1}$ and $\tilde{\theta_2}$. Hence, for any credible communication strategy $m$, we can construct a monotonic communication strategy $m''$.

Now, we compare the expected welfare obtained under strategies $m$, $m'$ and $m''$.

$$W_m(r) = -r\ ||\ \Theta_0\ ||+\gamma\ ||\ \Theta_1\ ||-\int_{\Theta_1}\theta d\theta \tag{33}$$

$$W_{m'}(r) = -r\ ||\ \Theta_0'\ ||+\gamma\ ||\ \Theta_1'\ ||-\int_{\Theta_1'}\theta d\theta \tag{34}$$

$$W_{m''}(r) = -r\ ||\ \Theta_0''\ ||+\gamma\ ||\ \Theta_1''\ ||-\int_{\Theta_1''}\theta d\theta \tag{35}$$

[31] Note that this definition is not ambiguous. First, if there exists $\theta_1$ and $\theta_2$ such that $\tilde{\theta_1}=\tilde{\theta_2}$ then the strategies $m'(\cdot,\theta_1)$ and $m'(\cdot,\theta_2)$ are identical. In addition, because $r^\star(\theta)$ is defined over a closed and bounded set, it is clear that the function that associates $\tilde{\theta}$ to $\theta$ covers the whole unit interval (hence $m''(\cdot,\theta$ is defined for all $\theta$).

[32] Either $\theta=\tilde{\theta}$ or there exists $\theta_1<\tilde{\theta}<\theta_2$ such that $r^\star(\theta_1)>r^\star(\theta)>r^\star(\theta_2)$, which ensures that the actions taken by individual $\theta$ when receiving message $m'(r,\theta)$ are the same as those taken by $\tilde{\theta}$.

To begin with, the first and second term of the right-hand-side of equations (34) and (35) are identical as, for all $r$, $m''$ only reorders the sets of responding agents without changing the volume of $\Theta_0(r)$ and $\Theta_1(r)$. The third term, however, is smaller in (35) than in (34) as, in every state, only the individuals with minimal types respond to the disaster. From this, we conclude that for all $r$, $W_{m''}(r) > W_{m'}(r)$.

Finally, $m'$ is obtained from $m$ by shifting the response of all individuals towards the largest states of nature. This transformation reduces the expected damage due to the catastrophe but does not affect the expected costs associated with individual responses or their external effects: we have $\mathbb{E}W_m < \mathbb{E}W_{m'}$[33], which implies that $\mathbb{E}W_m < \mathbb{E}W_{m''}$. We can thus restrict our analysis of private communication strategies to the set of monotonic strategies. □

*Proof of proposition 1.* Under private communication, the communication of the sender with any receiver characterized by type $\theta$ can result in two equilibria: a babbling equilibrium in which no information is disclosed, or an equilibrium in which the sender discloses whether the state of nature is above or below $\theta - \gamma$. Any other communication strategy involving two distinct messages on two different intervals would not be credible to the receiver due to the absence of commitment of the sender (who would have incentives to deviate).

When $\gamma < 0$, a necessary condition for an informative private communication equilibrium to be sustained is $\theta - \gamma < 1$, otherwise only one message is sent in equilibrium. With these receivers, the communication of the sender induces two different actions when:

$$\begin{cases} \mathbb{E}(r|r > \theta - \gamma) & > \theta \\ \mathbb{E}(r|r < \theta - \gamma) & < \theta \end{cases} \tag{36}$$

Because $\gamma < 0$, the first condition of equation (36) is always satisfied, and the second one is equivalent to $\theta > -\gamma$. Communication is possible with all $\theta \in [-\gamma; 1 + \gamma]$, which is non-empty if and only if $\gamma > -\frac{1}{2}$.

Likewise, when $\gamma > 0$, the second condition of equation (36) is always satisfied, and the first equation is equivalent to $\theta < 1 - \gamma$. For more than one message to be sent in equilibrium, we need $\theta - \gamma > 0$, which is satisfied when $\theta > \gamma$. Hence, communication is possible with all $\theta \in [\gamma; 1 - \gamma]$, which is non-empty when $\gamma < \frac{1}{2}$.

In addition, if communication is possible and if it induces two actions, the two actions coincide with the first-best outcome of the sender. Hence, when $\theta \in [|\gamma|; 1 - |\gamma|]$, the sender

[33] $W_{m'}$ may not dominate $W_m$ in each state of nature, as we alter the profile of individual responses.

strictly prefers informative communication to babbling.

We now turn to the expected welfare associated with private communication strategies. When $|\gamma| > 1/2$, the sender adopts a babbling strategy with all receivers, which is equivalent to babbling in the public case.

We now consider the expected welfare associated with the unique monotonic communication strategy adopted when $|\gamma| \in [0; \frac{1}{2}]$. The previous paragraphs ensure that the profile of actions is the following: all $\theta < |\gamma|$ take action 1, all $\theta > 1 - |\gamma|$ take action 0, and all $\theta \in [|\gamma|; |1-\gamma|]$ take action 1 if and only if $r < \theta - \gamma$.

In the case $\gamma > 0$, we thus have $\theta^\star(r) = r + \gamma$ if $r < 1 - 2\gamma$, and $\theta^\star(r) = 1 - \gamma$ otherwise. The equivalence between the profile of action of each type and the cut-off $\theta^\star(r)$ is illustrated in figure 4. Then, using equation (5), we have:

$$W(r) = \begin{cases} \frac{(r+\gamma)^2}{2} - r & \text{if } r < 1 - 2\gamma \\ -r\gamma + \gamma^2 - \frac{(1-\gamma)^2}{2} & \text{if } r > 1 - 2\gamma \end{cases} \tag{37}$$

Straightforward integration yields the following expression of the expected welfare $\mathbb{E}W_{private}(\gamma)$::

$$\mathbb{E}W_{private}(\gamma) = \begin{cases} -\frac{4\gamma^3}{3} + \frac{\gamma^2}{2} + \frac{\gamma}{2} - \frac{1}{3} & \text{if } \gamma \in [0; \frac{1}{2}] \\ \frac{\gamma}{2} - \frac{3}{8} & \text{if } \gamma \in [\frac{1}{2}; 1] \end{cases} \tag{38}$$

Similarly, when $\gamma < 0$, $\theta^\star(r) = r + \gamma$ if $r > -2\gamma$, and $\theta^\star(r) = -\gamma$ otherwise. Following the same steps, integration of $W(r)$ leads to:

$$\mathbb{E}W_{private}(\gamma) = \begin{cases} \frac{4\gamma^3}{3} + \frac{\gamma^2}{2} + \frac{\gamma}{2} - \frac{1}{3} & \text{if } \gamma \in [-\frac{1}{2}; 0] \\ \frac{\gamma}{2} - \frac{3}{8} & \text{if } \gamma \in [-1; -\frac{1}{2}] \end{cases} \tag{39}$$

The expected welfare under private communication is illustrated on figure 5. It is equal to the expected welfare from public communication when $|\gamma| > \frac{1}{2}$, and weakly larger when $|\gamma| < 1/2$[34]. This can easily be shown by comparing $\mathbb{E}W_{private}(\gamma)$ to the welfare obtained under public communication and under any credible communication strategy $\mathbb{E}W(n, \gamma)$. □

*Proof of corollary 3.* For any value of $\gamma$, the sender-preferred equilibrium[35] of the cheap-talk is

[34] Welfare is even strictly larger under private communication if we exclude the cases $\gamma \in \{0; -1/2; 1/2\}$.

[35] As discussed earlier, this makes sense as the equilibrium preferred by the sender for any $\gamma$ is both the most informative equilibrium and the equilibrium preferred by all receivers before learning their types.

considered. Using proposition 2, the expected welfare[36] associated with the cheap-talk game under externalities $\gamma$ is:

$$\mathbb{E}W_{\text{ex ante}}(\gamma) = \sup_{n\in\mathbb{N}}\{\mathbb{E}W(n,\gamma)\} \tag{40}$$

Now, notice that for any $n$, a necessary condition for the strategy characterized by $n$ messages to maximize expected welfare is that $\gamma < \frac{1}{2n(n-1)}$, which is always weakly smaller than the center of the associated polynomial. Hence, $\mathbb{E}W(n,\cdot)$ is necessarily increasing where it maximizes welfare, which implies that $\mathbb{E}W_{\text{ex ante}}$ is increasing (and quasi-concave) in $\gamma$. □

*Proof of corollary 4.* The expected welfare derived from the cheap-talk game is $\mathbb{E}W_{\text{ex ante}}(\gamma)$. Hence, the sender's investment in preparedness satisfies:

$$\gamma \in \operatorname*{argmax}_{\gamma'\in[-1;1]} \mathbb{E}W_{\text{prep}}(\gamma') = \mathbb{E}W_{\text{ex ante}}(\gamma') - \psi(|\gamma'-\gamma_0|) \tag{41}$$

Using corollary 3, the objective function defined by equation (41) is not necessarily quasi-concave, as the quasi-concavity of $\mathbb{E}W_{\text{ex ante}}(\cdot)$ is not preserved by the addition with $-\psi(\cdot)$. □

*Proof of proposition 3.* We first determine the expected welfare of the new cheap talk game, in which the externalities associated with the receivers' actions are measured by $\gamma$, while the communication strategies available to the sender correspond to those that would be played under externalities $\gamma' = \gamma - \Delta t$. Hence, noting $\theta_i'^{\star}$ the equilibrium outcomes associated with the new communication strategies available to the sender, and $r_i'$ their associated thresholds, the expression of the equilibrium expected welfare is:

$$\mathbb{E}W(n,\gamma,\Delta t) = \sum_{i=1}^{n}\int_{r'_{i-1}}^{r'_i}\left(-r(1-\theta_i'^{\star}) + \gamma\theta_i'^{\star} - \frac{\theta_i'^{\star 2}}{2}\right)dr \tag{42}$$

which leads to an updated version of equation (14):

$$\mathbb{E}W(n,\gamma,\Delta t) = \mathbb{E}W(n,\gamma) - \frac{(n^2+2)(\Delta t - 2\gamma)\Delta t}{6} \tag{43}$$

First, notice that for all $\Delta t$, the n-message equilibrium is incentive compatible if and only if $\gamma \in [\Delta t - \frac{1}{2n(n-1)}; \Delta t + \frac{1}{2n(n+1)}]$. Moreover, following the steps of the proof of corollaries 1 and 2, expected welfare increases with $n$ for any $\gamma$ and any $\Delta t$, and the most informative equilibrium is selected, then expected welfare is non-decreasing in $\gamma$. In addition, equation (43) shows that

[36] One could equivalently define $W_{\text{ex ante}}(\gamma)$ as the closure of the union of the convex hull of the graphs of $\mathbb{E}W(\gamma,n)$, which can be written $W_{\text{ex ante}}(\gamma) = \sup\{z | z \in \cup_{i\in\mathbb{N}} co(\mathbb{E}W(\gamma,i))\}$.

for all $n$ and all $\gamma$, expected welfare would be maximized by setting $\Delta t = \gamma$. However, this is impossible due to the budget constraint. Indeed, when $\gamma' = 0$, the sender-preferred equilibrium relies on a truthful communication strategy, and all receivers would ask for $t_0$ in state $r = 0$ or for $t_1$ in state $r = 1$, depending on the sign of $\gamma$. In both cases, the total transfer realized would be higher than $B$.

Hence, the best the sender can do is to maximize $t_0$ (keeping $t_1 = 0$) when $\gamma$ is negative, and maximize $t_1$ (keeping $t_0 = 0$) when $\gamma$ is positive. In each case, the budget constraint has to be binding in the states of nature in which the largest number of receivers request the transfer. When $\gamma < 0$, the constraint is binding when $r \in [0; r_1']$, as $1-\theta_1'^{\star}$ non-responding receivers benefit from transfer $t_0$. When $\gamma > 0$ the constraint is binding when $r \in [r_{n-1}'; 1]$, as $\theta_n'^{\star}$ responding receivers are eligible for transfer $t_1$. This yields:

$$\Delta t = \begin{cases} -t_0 = -\frac{B}{1-\theta_1'^{\star}} & \text{if } \gamma < 0 \\ t_1 = \frac{B}{\theta_n'^{\star}} & \text{if } \gamma > 0 \end{cases} \tag{44}$$

Finally, using the definition of $\theta_1'^{\star}$ and $\theta_n'^{\star}$ in equation (44) leads to the symmetric expressions of $t_0$ and $t_1$:.

$$t_1 = \frac{\gamma(n-1)}{2n} - \frac{2n-1}{4n^2} + \frac{1}{2n}\sqrt{\left(\frac{2n-1}{2n} - \gamma(n-1)\right)^2 + 4nB} \tag{45}$$

$$t_0 = -\frac{\gamma(n-1)}{2n} - \frac{2n-1}{4n^2} + \frac{1}{2n}\sqrt{\left(\frac{2n-1}{2n} + \gamma(n-1)\right)^2 + 4nB} \tag{46}$$

$\square$

*Proof of corollary 5.* Equation (26) is directly obtained by combining equation (24) and the Bayesian rationality constraints. This implies that choosing a credible threshold ex ante fully determines the amount of the transfers made ex post (or at least their difference $\Delta t$). Thus, we solve the optimization problem of the sender by considering the transfers as her sole decision variable. The optimization problem is to choose the amount of the transfers in order maximize expected welfare, while satisfying the budget constraint. Expected welfare is here defined as:

$$\mathbb{E}W(\Delta t, r_0, \gamma) = \int_0^{r_0} W(r, \theta_1^{\star})dr + \int_{r_0}^{1} W(r, \theta_2^{\star})dr \tag{47}$$

To solve this problem, we focus on the case of negative externalities. We can restrict to the cases in which $t_1 = 0$ and $t_0 > 0$. If the solution to our problem entails both types of transfers, then the sender can reduce both types of transfers by the same amount without modifying expected welfare, which only depends on $\Delta t$. As we assume that $\gamma > 0$, we necessarily have $t_0 > t_1$, so that we can decrease $t_1$ until it is null and the sender only subsidizes people who cannot take the protective action. $\square$

*Proof of corollary 6.* As equation (28) is a quadratic constraint with positive coefficient, this problem consist in maximizing the expression shown in equation (27) over a closed interval that we note $[0; t_+]$.[37] This problem always has a strictly positive solution, which can be either the upper corner solution $t_+$ or the unconstrained maximizer of equation (27), noted $t_0^\star$. These two quantities can be explicitly calculated:

$$t_0^\star = \frac{4\gamma}{3} - \frac{1}{4} + \frac{1}{3}\sqrt{4\gamma^2 + \frac{16}{9}} \tag{48}$$

$$t_+ = \frac{\gamma}{3} - \frac{1}{12} + \frac{1}{3}\sqrt{(\frac{1}{4} - \gamma)^2 + 6B} \tag{49}$$

Simple manipulations show that $t_+ > t_0^\star$ if $B$ is superior to a minimum budget $B_{min}$. $\square$

[37] The interval is closed because the constraint can be binding. $t_+$ is the unique positive root of the polynomial defined by equation (28), which explains why the other end of the constrained interval is 0.

## References


Allon, G., Bassamboo, A., and Gurvich, I. (2011). “We will be right with you”: Managing customer expectations with vague promises and cheap talk. *Operations research*, 59(6):1382–1394.

Antic, N. and Persico, N. (2016). Communication among shareholders. *Working Paper*.

Battaglini, M. (2002). Multiple referrals and multidimensional cheap talk. *Econometrica*, 70(4):1379–1401.

Battaglini, M. and Makarov, U. (2014). Cheap talk with multiple audiences: An experimental analysis. *Games and Economic Behavior*, 83:147 – 164.

Bauch, C. T. and Earn, D. J. D. (2004). Vaccination and the theory of games. *Proceedings of the National Academy of Sciences*, 101(36):13391–13394.

Brito, D. L., Sheshinski, E., and Intriligator, M. D. (1991). Externalities and compulsary vaccinations. *Journal of Public Economics*, 45(1):69–90.

Che, Y.-K., Dessein, W., and Kartik, N. (2013). Pandering to persuade. *The American Economic Review*, 103(1):47–79.

Che, Y.-K. and Kartik, N. (2009). Opinions as incentives. *Journal of Political Economy*, 117(5):815–860.

Chen, Y., Kartik, N., and Sobel, J. (2008). Selecting cheap-talk equilibria. *Econometrica*, 76(1):117–136.

Coate, S. (1995). Altruism, the samaritan’s dilemma, and government transfer policy. *The American Economic Review*, pages 46–57.

Cole, T. W. and Fellows, K. L. (2008). Risk communication failure: A case study of new orleans and hurricane katrina. *Southern Communication Journal*, 73(3):211–228.

Crawford, V. P. and Sobel, J. (1982). Strategic information transmission. *Econometrica*, pages 1431–1451.

Farrell, J. and Gibbons, R. (1989). Cheap talk with two audiences. *The American Economic Review*, 79(5):1214–1223.

Figueroa, P. M. (2013). Risk communication surrounding the fukushima nuclear disaster: an anthropological approach. *Asia Europe Journal*, 11(1):53–64.

Gardete, P. M. and Bart, Y. (2017). Tailored cheap-talk. Working paper.

Geoffard, P.-Y. and Philipson, T. (1997). Disease eradication: Private versus public vaccination. *The American Economic Review*, 87(1):222–230.

Goltsman, M. and Pavlov, G. (2011). How to talk to multiple audiences. *Games and Economic Behavior*, 72(1):100–122.

Hasegawa, R. (2013). Disaster evacuation from japan’s 2011 tsunami disaster and the fukushima nuclear accident. *SciencesPo - IDDRI Study*.

Heal, G. and Kunreuther, H. (2005). The vaccination game. *Wharton Risk Management and Decision Processes Center Working Paper*, (05-10).

Kamenica, E. and Gentzkow, M. (2011). Bayesian persuasion. *The American Economic Review*, 101(6):2590–2615.

Kawamura, K. (2011). A model of public consultation: why is binary communication so common? *The Economic Journal*, 121(553):819–842.

Koessler, F. (2008). Lobbying with two audiences: Public vs private certification. *Mathematical Social Sciences*, 55(3):305–314.

Krishna, V. and Morgan, J. (2001). A model of expertise. *The Quarterly Journal of Economics*, 116(2):747–775.

Krishna, V. and Morgan, J. (2004). The art of conversation: eliciting information from experts through multi-stage communication. *Journal of Economic theory*, 117(2):147–179.

Kunreuther, H. (1996). Mitigating disaster losses through insurance. *Journal of risk and Uncertainty*, 12(2):171–187.

Kunreuther, H. (2006). Disaster mitigation and insurance: Learning from Katrina. *The Annals of the American Academy of Political and Social Science*, 604(1):208–227.

Kunreuther, H., Meyer, R., and Michel-Kerjan, E. (2013). *The Behavioral Foundation of Policy*, chapter Overcoming Decision Biases to Reduce Losses from Natural Catastrophes, pages 398–413. Princeton University Press.

Laclau, M. and Renou, L. (2016). Public persuasion. Working paper.

Lukyanov, G. and Su, T. (2017). Coordination frictions and public communication. Working paper.

Palttala, P., Boano, C., Lund, R., and Vos, M. (2012). Communication gaps in disaster management: Perceptions by experts from governmental and non-governmental organizations. *Journal of Contingencies and Crisis Management*, 20(1):2–12.

Perko, T. (2011). Importance of risk communication during and after a nuclear accident. *Integrated environmental assessment and management*, 7(3):388–392.

Pljansek, K., Ferrer, M., De Groeve, T., and Clark, I. (2017). Science for disaster risk management 2017: Knowing better and losing less. Technical report, European Commission Joint Research Center - Disaster Risk Management Knowledge Centre.

Portney, P. R. (1992). Trouble in happyville. *Journal of Policy Analysis and Management*, 11(1):131–132.

Ramana, M. (2011). Beyond our imagination: Fukushima and the problem of assessing risk. *Bulletin of the atomic scientists*, 19:37–62.

Reynolds, B. and Seeger, M. W. (2005). Crisis and emergency risk communication as an integrative model. *Journal of health communication*, 10(1):43–55.

Salanié, F. and Treich, N. (2009). Regulation in happyville. *The Economic Journal*, 119(537):665–679.

Seeger, M. W. (2006). Best practices in crisis communication: An expert panel process. *Journal of Applied Communication Research*, 34(3):232–244.

Steelman, T. A. and McCaffrey, S. (2013). Best practices in risk and crisis communication: Implications for natural hazards management. *Natural Hazards*, 65(1):683–705.

Teh, T.-L. (2017). Insurance design in the presence of safety nets. *Journal of Public Economics*, 149:47–58.

Trager, R. F. (2010). Diplomatic calculus in anarchy: How communication matters. *American Political Science Review*, 104(2):347–368.

Wang, Y. (2015). Bayesian persuasion with multiple receivers. Working paper.

Zhang, H., Yan, W., Oba, A., and Zhang, W. (2014). Radiation-driven migration: the case of minamisoma city, fukushima, japan, after the fukushima nuclear accident. *International journal of environmental research and public health*, 11(9):9286–9305.