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Communication Failure: The Hidden Face of the Tragedy of the Commons

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COMMUNICATION FAILURE: THE HIDDEN FACE OF THE TRAGEDY OF THE COMMONS*

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This paper studies communication failure regarding risks in the commons. It argues that strategic issues might explain why years of scientific reporting regarding future risks have failed to trigger sufficient climate awareness. We consider a game of contribution to a public bad, where there is uncertainty regarding the damage generated by externalities. Prior to the game, agents receive non-certifiable information regarding the damage from an informed utilitarian expert. We show that in large-scale public good problems information transmission usually fails. We compare this result with the cases of Rawlsian and anti-Rawlsian experts and discuss the implication for climate expert panels. We also investigate the influence of the value of information in our result, which provides us with some insight on the part played by deontology on scientific communication.

Keywords: Public good games, Cheap Talk, Climate Change, Values in Science

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1. Introduction

Public good games and the problem of externalities is one of the most studied collective action problem in economics. The social challenges accompanying them are among the most pressing of our time, ranging from public adoption of anti-pandemic measures to patent sharing and open science policies. Accounting for uncertainty in public good games is essential to understand a large variety of situations: excessive use of antibiotics, local pollution and biodiversity losses or greenhouse gas (GHG) emissions and their effect on global warming.[1] In many of these cases, one striking observation is that risks are often misperceived by the concerned population, despite experts' efforts to raise awareness on the matter. This is for instance the case regarding long term consequences of climate-change[2] or risks resulting from the use of mRNA vaccines.[3] This paper shows how perceived difference of interests between the scientific community and the general population in public good games can undermine communication and be responsible for this misperception of risk.

In the following, we focus on climate risk as our main application. We consider a communication game followed by a game of contribution to a public bad. In the contribution game, n identical agents simultaneously and non-cooperatively decide on a level of individual contribution which positively affects their private benefit but also generates negative externalities by contributing to a public bad that imposes a cost common to all agents. While agents are certain about the value of the private benefit, we assume they are uncertain about the exact cost of the public bad.[4] For example, countries choosing their production level – and hence their level of greenhouse gas (GHG) emissions – may evaluate well the benefits in terms of GDP but, due to the complexity of climate change, may perceive only very imperfectly the cost of global emissions. Prior to the contribution game, an expert who has private information about the cost of the public bad sends a public message to the group of n agents. We assume that the information provided by the expert is not verifiable, making communication a cheap-talk game.[5] Whether the expert can effectively inform the agents about the severity of the externalities is therefore a question of credibility: agents will believe in a message only if they know the expert benefits from sending it. Therefore, a central ingredient of our model is the assumed normative goal of the expert. In the baseline model we rely on the standard assumption that the expert is a utilitarian planner seeking to maximise the sum of the agents' utilities. Despite its apparent closeness with each agent's

[1] For more examples and details on the magnitude of these problems, see the Millennium Ecosystem Assessment Report (Assessment, 2005).

[2] Sterman (2008) famously showed how hard it is for MIT students to draw a causal link between the multiple potential causes of climate change and their consequences.

[3] Hornsey, Lobera and Díaz-Catalán (2020) showed that the sudden increase in distrust regarding vaccination during the COVID-19 crises is best explained by a distrust in political and pharmaceutical actors.

[4] Formally, we assume that the contribution game is one of strategic substitutes and we consider its Bayes-Nash equilibrium.

[5] The case of GHG emissions and climate change is a good example: Although scientific results regarding their effect are well established for scientists, for non-scientists the knowledge needed to assess the precise effect of one's action is simply too vast. Lorenzoni and Pidgeon (2006) surveyed a large sample of citizens in Europe and the USA and showed that most people have limited knowledge about climate change and mostly relate to it through trust in experts.

utilities, the expert's preferences exhibit two sources of misalignment. First, the expert is initially perfectly informed about the exact social cost of the externalities whereas agents only know the average value of the cost they will face. Second, while each agent only cares about how much the public bad affects them individually, the expert cares about the full extent of the cost of the public bad as they fully internalise the externalities generated by individual contributions.

Our main result is to provide a simple characterization of the determinants of the failure of information transmission. We show that a high number of contributors, a low individual marginal impact of the damage, and limited uncertainty regarding the damage are three key determining factors responsible for failure of information transmission. Regrettably, all three causes are characteristic of large-scale public good problems, such as GHG emissions: the number of agents is extremely high, individual marginal damages are very limited and uncertainty regarding the effects of climate change is small. The key point is that all three causes listed above increase the discrepancy between each individual private cost of the externalities and the aggregate social cost considered by the expert. If this discrepancy is too large, agents foresee that the expert would always have an incentive to exaggerate the damage. As a result, the expert becomes a non-credible source of information and communication fails. It is important to note that communication failure in our model does not mean experts stay silent on the effect of GHG emissions. Rather, our result suggests that they "*speak into the wind*": any of their claim is ignored by contributors. We believe that, in practice, experts are telling the truth about what they know. The strength of our model is to show that the strategic setting leads them to be ignored by their audience. Empirical evidence supports this claim. Lupia (2013) shows, using both laboratory and survey experiments, that perceived difference of interests and perceived expertise are sufficient to predict a source's credibility. Once these two factors are accounted for, partisan identification and ideological alignment lose all residual explanatory power. Mildenberger et al. (2022) provide complementary field evidence: effective information provision on climate policies is mainly determined by perceived alignment of interest, independently of perceived competence, with public perceptions remaining mostly structured by assessments of whose interests the expert serves rather than by the informational content of the message itself.

A central element leading to our main result is the assumed normative objective of the expert. An important body of work in the philosophy of science has documented that scientific assessments, far from being purely factual, inevitably reflect such normative choices (Douglas, 2000): experts must decide how to aggregate individual welfare, how to weight present versus future costs, or how much risk of being wrong they are willing to tolerate before issuing a recommendation. These choices embed value judgments that may diverge from those held by the audiences experts address (Elliott, 2017, Winsberg, 2012, Intemann, 2015). This is particularly consequential when comes to climate change, where the choice of social discount rate (Stern, 2007, Nordhaus, 2007) or the treatment of low-probability, high-damage scenarios (Weitzman, 2009) reflects deep normative disagreements about intergenerational equity and distributional fairness (Weisbach and Sunstein, 2009, John, 2017). In particular Schroeder (2021) argues that once an audience recognises that an expert's assessments rest on such normative choices, perceived divergence between the expert's normative criterion and the audience's own values constitutes a rational reason to discount the expert's message—even when the expert is fully competent and has no ulterior motive. Our model provides a formal argument for this mechanism. Relying on a parametric version of our model, we compare our baseline assumption of utilitarian expert with alternative normative objectives. We consider side-taking experts, either Rawlsian (maximising the utility of the agents most exposed to damage) or anti-Rawlsian (maximising the utility of agents less exposed to damage). We show that heterogeneity of preferences across agents favours communication in the utilitarian and Rawlsian cases but not in the anti-Rawlsian one, and that the existence of an informative equilibrium when the expert is anti-Rawlsian implies it when the expert is utilitarian, which further implies it when the expert is Rawlsian. These results shed light on the informational virtues of different ethical positions that could reflect in different compositions of climate expert panels: Rawlsian (anti-Rawlsian) experts can be seen as favouring the interests of the more (less) exposed agents of the Global South (North), and our ordering result characterises which normative objectives are most conducive to credible communication.

Finally, we investigate the connection between the existence of credible information transmission and its value to the expert. It could indeed be tempting to believe that information transmission is entirely determined by its value at equilibrium. To abstract away from strategic constraints and focus only on the value of information, we rely on *Bayesian persuasion* techniques (Kamenica and Gentzkow, 2011). We show that there are cases where information provision would be welfare improving for a utilitarian expert, but the strategic setting makes any of her claims non-credible. On the contrary, there are cases where a utilitarian expert can provide information in a strategically credible way, but would not ex ante benefit from it. We find these latter cases remarkable, because they depict situations where informational and welfarist goals go in different ways. We believe that it is in the choice between these goals that scientific deontology plays its part. Scientific deontology compels the expert to convey as much information as possible to their audience. Yet, we show that assuming the expert accounts for welfarist considerations, at least alongside informational ones, makes full revelation non-credible. Scientific deontology can only play a part in selecting across equilibrium strategies. When informational goals conflict with welfarist ones, deontology will direct scientists to favour informational equilibria over welfare improving ones

Related Literature— The game of contribution to a public bad we study is in the tradition of the canonical public good game of Bergstrom, Blume and Varian (1986). It also encompasses the version studied in the context of GHG emissions and climate change such as Barrett (1994) and Diamantoudi and Sartzetakis (2006). Our paper also relates to the study of uncertainty in public good games and is in the line of Bramoullé and Treich (2009) who show that uncertainty can be useful to alleviate the externality problem.[6]

Our model also contributes to the literature on climate-related communication and awareness.

[6]See Angeletos and Pavan (2007) for a more systematic review of games where information can have a negative value.

Asheim (2010) was the first to study information transmission in the context of public good games. In his model, a benevolent environmental agency can certify information about climate risk to the contributors. He shows that full revelation is not always optimal for the environmental agency. In the same vein, Kakeu and Johnson (2018) study information exchange between privately-informed countries in a model of transnational pollution. Information transmission is certifiable but costly. They show that sharing information is only incentive-compatible under sufficiently precise private information. Slechten (2020) finds similar results regarding the role of (certifiable) information-sharing regarding abatement costs prior to an environmental agreement. Only when uncertainty is high enough will information transmission through the use of a mechanism be desirable for participants. The results of the present paper are in line with the general idea conveyed by this literature: the fact that information does not always have a positive value in games of contribution to a public good may impact communication.

Finally, our model contributes to the sender-receiver cheap-talk literature in the tradition of Crawford and Sobel (1982), exploring to the case of multiple receivers whose actions generate payoff externalities. In doing so, we provide a natural reason for communication bias as resulting from the normative view the sender holds regarding the externalities on the receivers' side. To our knowledge, Dietrich, Le Quement and Tvede (2022) are the only ones to also study interaction among receivers after a cheap-talk communication phase. Their results are complementary to ours, and focus more on sufficient conditions for communication and welfare maximisation than on understanding communication failure. Goltsman and Pavlov (2011) also study cheap talk with public and private communication with multiple receivers, but they do not allow for receivers' actions to affect each other. A second theoretical novelty introduced by our paper is to provide a characterisation result in the context of a cheap-talk game where the misalignment between parties is not linear, as generally assumed in applications. Our results also resonate with Farrell and Gibbons (1989) who show, in a somewhat different setting, that the presence of additional receivers affects the sender's strategy, and with Battaglini and Makarov (2014), who studied cheap-talk communication with multiple receivers in an experimental setting. Our work also relates to the information design literature (Kamenica and Gentzkow, 2011) and its recent application to the Intergovernmental Panel on Climate Change's (IPCC) communication (Vosooghi and Caparrós, 2022). We use this methodology to bring out situations where the expert's expected payoff benefits from a general form of information provision, and show that they do not intersect, in general, with credibility in communication. Cheap-talk communication has practically not been applied to public good games so far. One possible explanation is that the literature has not yet identified interesting applications for such models. Beyond climate communication, we believe many real world cases can be better understood through theses lenses, such as central bank or public health communications. We provide a detailed explanation in section 6. A second explanation is the theoretical challenge posed by providing tractable results in a general enough public good setting. Communication games *à la* Crawford and Sobel (1982) are notoriously difficult to keep tractable once leaving the classical linear-quadratic parametric form over which most applications rely (Lagerlöf, 2007, Duffy, Heinemann and Nagel, 2021), one of the challenges taken up by this paper.

Section 2 introduces the base model and focuses on the public bad contribution problem. Section 3 establishes the main results on communication failures. Section 4 discusses alternative assumptions on the expert's objectives and Section 5 explores the role of the value of information in our game. Section 6 discusses the relevance of our results and Section 7 concludes. All proofs are relegated to the appendix.

2. The Contribution Game

Consider a game between an expert and n agents, indexed by $i \in N := \{1, \ldots, n\}$. Each agent i chooses an action $e_i \in \mathbb{R}_+$ that generates a private benefit $B(e_i)$ and contributes to social damages $D(e)$, where $e := (e_1, \ldots, e_n) \in \mathbb{R}^n_+$ is the vector of all agents' actions. The severity of the damage also depends on the realisation of an exogenous parameter, $\omega \in \Omega := [a,b] \subseteq \mathbb{R}_+$, where a and b represent the least and most pessimistic values for the state of the world, respectively. The agent i's disutility of the damage is given by $\varphi_i(\omega)D(e)$, where φ_i is strictly positive, continuous and increasing in ω. We refer to ω as the *state of the world* and to φ_i as the *individual scale effect* due to uncertainty. We call $\sum_{j\in N} \varphi_j$ the *social scale effect*.

The utility of agent i is given by

$$u_i(e_i, e_{-i}; \omega) := B(e_i) - \varphi_i(\omega)D(e_i, e_{-i}),$$

where $(e_i, e_{-i}) \in \mathbb{R}^n_+$ is a convenient alternative notation for e. We further assume that B and D are twice continuously differentiable, where $\frac{\partial B}{\partial e_i} > 0$, $\frac{\partial^2 B}{\partial e_i^2} \leq 0$, $\frac{\partial D}{\partial e_i} > 0$, $\frac{\partial^2 D}{\partial e_i^2} > 0$, $\frac{\partial^2 D}{\partial e_i \partial e_j} > 0$, and D is symmetric for all $(e_i, e_{-i}) \in \mathbb{R}^n_+$, $i \in N$ and $j \neq i$. The assumption of risk aversion is often made when studying contribution to GHG emissions, for instance in Bramoullé and Treich (2009). Given the magnitude of potential damages created by climate change, Heal and Kriström (2002) argue that agents display risk aversion in their decision making. This assumption is similarly made in the literature on integrated assessment models, for instance in Nordhaus (1994) or Stern (2007).

The expert is an utilitarian social planner, that is, her utility is defined as the sum of the agents' utilities, $v(e;\omega) := \sum_{j\in N} u_j(e;\omega)$, or equivalently,

$$v(e;\omega) = \sum_{j\in N} B(e_j) - D(e) \sum_{j\in N} \varphi_j(\omega)$$

where the second term follows from the symmetry of the social damage function $D(e)$. Under these assumptions, it is clear that the problem exhibits negative externalities and free-riding effects as each agent i is concerned only with the individual scale effect $\varphi_i(\omega)$ while the expert cares about the social scale effect $\sum_{j\in N} \varphi_j(\omega)$.

For now, we will assume for simplicity that the individual scale effect is symmetric across agents, that is, $\varphi_i := \varphi$ for all $i \in N$. In that case, notice that the social scale effect simplifies to

$\sum_{j \in N} \varphi(\omega) = n\varphi(\omega)$ but we may often keep the notation $\sum_{j \in N} \varphi(\omega)$ for clarity of exposition. We investigate asymmetric individual scale effects in Section 4.

Example— Our agent's utility specification is general and flexible enough to accommodate the applications we have in mind. For instance, it is compatible with the assumptions of Bramoullé and Treich (2009), and a similar formalisation can be found in Helm and Wirl (2014). The following functional form provides an illustration of a possible utility function and anticipates our applications in Sections 4 and 5. Let

$$u_i(e_i, e_{-i}; \omega) = \left(e_i - \frac{e_i^2}{2}\right) - \gamma_i \phi(\omega) \frac{1}{2} \left(\sum_{j \in N} e_j\right)^2, \tag{1}$$

where the private benefit is $B(e_i) = e_i - \frac{e_i^2}{2}$, the common damage $D(e_i, e_{-i}) = \frac{1}{2}\left(\sum_{j \in N} e_j\right)^2$, and the individual scale effect of the damage $\varphi_i(\omega) = \gamma_i \phi(\omega)$. For instance, this specification is almost identical to that used by Diamantoudi and Sartzetakis (2006).[7]

We now introduce the key assumption of the paper: The state of the world, ω, is private information to the expert. That is, we assume that only the expert perfectly observes ω whereas agents only have a common differentiable prior belief $p_0 \in \Delta(\Omega)$ about its distribution.

To shed some light on the role of incomplete information in our framework, we abstract for now from the communication game between the expert and the agents. Instead, we simply assume that agents hold a posterior belief $p \in \Delta(\Omega)$ about the distribution of ω, where $\Delta(\Omega)$ denote the set of Borel probability measures on Ω.[8] This allows us to focus on the consequences of different posterior beliefs on the agents' equilibrium actions and the resulting expert's utility regardless of the strategic considerations of communication.

We let $\mathbb{E}_p$ denote the expectation operator with respect to belief p. Notice that if $p = p_0$, $\mathbb{E}_{p_0}$ indicates that agents average over values of ω only with their prior information. With a slight abuse of notation, we will say that agents hold posterior belief ω when they are perfectly informed about the state of the world.[9]

When agents hold posterior beliefs $p \in \Delta(\Omega)$, we denote their expected utility by $U_i(e_i, e_{-i}; p) := \mathbb{E}_p u_i(e_i, e_{-i}; \omega)$. Agent i chooses their action to solve $\max_{e_i \in \mathbb{R}_+} U_i(e_i, e_{-i}; p)$, or equivalently,

$$\max_{e_i \in \mathbb{R}_+} B(e_i) - \mathbb{E}_p[\varphi(\omega)] D(e_i, e_{-i}). \tag{2}$$

[7]The only significant difference is that they define the private benefit as $B(e_i) = \theta[te_i - \frac{e_i^2}{2}]$ which corresponds to set $\theta = t = 1$ in our case.

[8]This posterior belief can be seen as the result of some communication protocol in which the expert has sent a *credible* public signal $s \in \Delta(\Omega)$. Agents observe the signal and update their prior belief p_0 to p.

[9]Formally, if an agent perfectly observes the actual state of the world $\omega \in \Omega$, they have a *degenerate* posterior belief p_ω where all the probability mass is on ω.

The best-response function of agent i is given by the first-order condition of the above problem:[10]

$$\frac{\partial B(e_i)}{\partial e_i} = \mathbb{E}_p[\varphi(\omega)]\frac{\partial D(e_i, e_{-i})}{\partial e_i}, \tag{3}$$

that is, agent i simply equates the private marginal benefit of their action with their expected private marginal cost. A particular case of this problem is when agents are perfectly informed about ω. In that case, their best-response function is characterised by equation (3) where $\mathbb{E}_p[\varphi(\omega)]$ is replaced by $\varphi(\omega)$.

Let $e(p) := \big(e_i(p), e_{-i}(p)\big)$ denote the equilibrium action profile of the unique symmetric Nash equilibrium of the agents' game under posterior belief p. That is, for any given p, we have $e_i(p) = e_j(p)$ for all i and j, and $(e_i(p), e_{-i}(p))$ solves equation (3). Using the previous notation, we will denote by $e(\omega) := \big(e_i(\omega), e_{-i}(\omega)\big)$ the equilibrium action profile when the state of the world is ω and agents perfectly observe it.

Consider now what would be the expert's preferred level of individual actions. Formally, the expert's problem is defined as follows:

$$\max_{e \in \mathbb{R}^n_+} \sum_{j \in N} B(e_j) - D(e) \sum_{j \in N} \varphi(\omega), \tag{4}$$

which leads to the following optimality condition for each e_i:

$$\frac{\partial B(e_i)}{\partial e_i} = \sum_{j \in N} \varphi(\omega) \frac{\partial D(e_i, e_{-i})}{\partial e_i}. \tag{5}$$

Let $e^W(\omega) := (e^W_i(\omega), e^W_{-i}(\omega))$ denote the expert's preferred level of actions for each realisation of the state of the world ω. We naturally expect $e^W(\omega)$ to differ from the Nash equilibrium $e(p)$ for two reasons: (i) the expert fully internalises the externalities among the agents, and (ii) the expert has full information about the state of the world. We now proceed to disentangle these two effects in order to better understand how the agents' uncertainty about the state of the world can be beneficial to the expert.

Proposition 1. *Assume $\varphi_i = \varphi$ for all $i \in N$. If all agents perfectly observe the state of the world, ω, then $e_i(\omega) \geq e^W_i(\omega)$ for all $\omega \in \Omega$ and $i \in N$.*

That is, under perfect information on the state of the world, there is *overprovision* with respect to the expert's preferred action levels. Proposition 1 captures the pure free-riding effects of the problem through the difference $e_i(\omega) - e^W_i(\omega) \geq 0$.

However, as agents will typically be imperfectly informed about the state of the world, we ultimately want to compare $e^W_i(\omega)$ to $e_i(p)$ for any belief p. First, it is useful to notice that both the expert's and the agents' preferred action levels are decreasing in the state of the world, either observed or expected. The following result makes this statement precise.

[10] Notice that our assumptions on the agents' utility function ensure that (i) the solution to (3) is unique and (ii) that first-order conditions are both necessary and sufficient as $\frac{\partial^2 U_i(e_i, e_{-i}; p)}{\partial e_i^2} = \frac{\partial^2 B(e_i)}{\partial e_i^2} - \mathbb{E}_p[\varphi(\omega)]\frac{\partial^2 D(e_i, e_{-i})}{\partial e_i^2} < 0$.

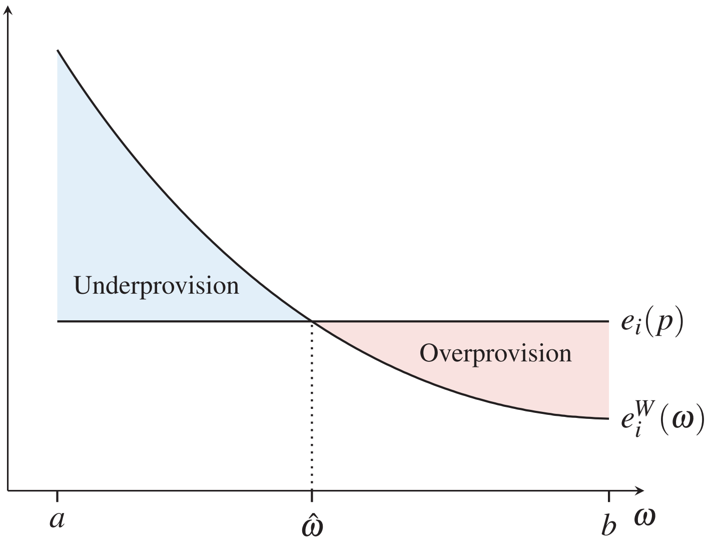


Figure 1: The figure represents how each type of expert ($\omega \in \Omega$) perceives the equilibrium action levels of agents with belief $p \in \mathscr{P}(\hat{w})$ with respect to the socially optimal action level.

Proposition 2. *Assume $\varphi_i = \varphi$ for all $i \in N$. For any $i \in N$, take ω, ω' such that $\omega' \geq \omega$, then $e_i^W(\omega') \leq e_i^W(\omega)$. Similarly, take any two beliefs p and p' such that $\mathbb{E}_{p'}[\varphi(\omega)] \geq \mathbb{E}_p[\varphi(\omega)]$, then $e_i(p') \leq e_i(p)$.*

Finally, let

$$\mathscr{P}(\omega) := \{p \in \Delta(\Omega) \mid \mathbb{E}_p[\varphi(\tilde{\omega})] = n\varphi(\omega)\}$$

denote the set of beliefs such that the expected individual scale effect is equal to the social scale effect when the state of the world is ω.

It immediately follows that when agents hold a belief $\hat{p} \in \mathscr{P}(\hat{\omega})$, then $e_i(\hat{p}) = e_i^W(\hat{\omega})$. That is, under belief $\hat{p}$ the equilibrium action level of each agent is equal to the socially optimal action at $\omega = \hat{\omega}$. Combining this last observation with Proposition 2, it follows that the expert should expect *overprovision* (resp. *underprovision*) whenever the actual state of the world ω is greater (resp. lower) than $\hat{\omega}$ under beliefs $\hat{p}$. Figure 1 illustrates the overprovision and underprovision regions with respect to the expert's preferred action levels. Alternatively, it means that the expert would benefit from making the agents more *pessimistic* about the state of the world when there is overprovision ($\omega > \hat{\omega}$) and more *optimistic* when there is underprovision ($\omega < \hat{\omega}$).

As we will see in the next section, the credibility of the expert will crucially depend on whether both underprovision and overprovision are a possible outcome from the point of view of the agents.

3. Communication

While the previous observations give an overview of the potential benefits of communication for the expert, they abstract from the problem of the expert's credibility. Indeed, when agents anticipate that the expert may have an interest in manipulating their beliefs about the state of the world, they might simply not believe in what the expert communicates.

We now investigate this issue by assuming that, prior to the game among agents, the informed expert can send a message $m \in \mathscr{M}$, where $\mathscr{M}$ is a non-degenerate interval of $\mathbb{R}$. Each agent i observes message m, forms their posterior belief about the state of the world ω and then chooses their action level e_i. We further assume that communication is costless and public.

Formally, the expert chooses a communication strategy $\sigma : \Omega \to \mathscr{M}$ which is a measurable map that assigns a message to each level of the state of the world. A strategy for agent i is a measurable map $y_i : \mathscr{M} \to \mathbb{R}_+$ that assigns an action level to each message. We rely on perfect Bayesian equilibrium as a solution concept. Upon observing message $m \in \mathscr{M}$, agent i forms their posterior belief $p_m \in \Delta(\Omega)$ where p_m is derived from Bayes' rule, whenever possible.[11] Agent i chooses $y_i(m) = e_i(p_m) = \arg\max_{e_i} \mathbb{E}_{p_m}[u_i(e_i, e_{-i}(p_m); \omega)]$ where $e_i(p_m)$ corresponds to the symmetric Nash equilibrium action of agent i under posterior belief p_m. Finally, the expert chooses $\sigma(\omega) \in \arg\max_{m \in \mathscr{M}} v(e(p_m); \omega)$ for all $\omega \in \Omega$. Throughout, we restrict attention to symmetric perfect Bayesian equilibria.

In this environment, the communication protocol can be seen as a cheap-talk game with one sender (the expert) and multiple receivers (the agents). In the following, we restrict attention to partition equilibria. Without loss of generality, we assume that $\mathscr{M} = \Omega$ and investigate K-partition equilibria. For any $K \geq 2$, the expert's strategy consists in choosing $K-1$ cutoff points $(\omega_1, \ldots, \omega_{K-1}) \in \Omega^{K-1}$ such that at equilibrium sending message $m_k = \omega_k$ induces agents to believe that $\omega \in [\omega_{k-1}, \omega_k)$ for $k = 1, \ldots, K-1$ and $\omega \in [\omega_{K-1}, \omega_K]$ for $k = K$, where endpoints are defined by $\omega_0 := a$ and $\omega_K := b$. There always exists a partition equilibrium with $K = 1$,[12] which we refer to as *a noninformative communication equilibrium.*[13]

We show below that the presence of externalities severely precludes the existence of informative communication equilibria, that is, the existence of communication equilibria with $K \geq 2$ partitions.

Symmetric agents— For now, we assume that agents are symmetric in the sense that $\varphi_i = \varphi$ for all $i \in N$. Consider the case of a 2-partition equilibrium in which the expert has to choose one cutoff point $\omega_1 \in \Omega$ and send either message m_1 when $\omega \in [a, \omega_1)$ or message m_2 when $\omega \in [\omega_1, b]$. For ω_1 to be an equilibrium cutoff point, it must be the case that an expert of type $\omega \in [a, \omega_1)$ prefers m_1 to m_2, that one of type $\omega \in (\omega_1, b]$ prefers m_2 to m_1, and that type $\omega = \omega_1$ is indifferent between m_1 to m_2. For this last statement to be true, it is necessary that the posterior

[11] Formally, having received an equilibrium public message $m \in \text{supp}(\sigma)$, agent i updates their prior using Bayes' rule such that:

$$p(\omega \mid m) = \begin{cases} \frac{p_0(\omega)}{\int_{\sigma^{-1}(m)} p_0(\omega) d\omega} & \text{if } \omega \in \sigma^{-1}(m) \\ 0 & \text{otherwise.} \end{cases}$$

Any message m such that $m \notin \text{supp}(\sigma)$ is interpreted as some equilibrium message $m^* \in \text{supp}(\sigma)$.

[12] Formally, there is no interior cutoff point and the only message the expert can send is $m_1 = \omega_1$ such that the agents must believe that $\omega \in [\omega_0, \omega_1] = [a, b]$, that is, the message is uninformative.

[13] Crawford and Sobel (1982), Theorem 1.

belief induced by m_1 gives the same utility to the expert that the posterior belief induced by m_2. This requirement is directly related to the existence of underprovision and overprovision regions as the following result shows.

Define the expert's utility directly as a function of the expected individual scale effect induced by belief p as follows $\tilde{v}(\mathbb{E}_p[\varphi(\tilde{\omega})];\omega) := v(e(p);\omega)$.

Lemma 1. *There exists $x, x' \in [\varphi(a), \varphi(b)]$ such that $\tilde{v}(x;\omega) = \tilde{v}(x';\omega)$ at ω only if $\mathscr{P}(\omega) \neq \varnothing$. Moreover, x and x' satisfy $x < n\varphi(\omega) < x'$.*

It means that for ω_1 to be a valid cutoff point in a 2-partition equilibrium there must exist some belief $p \in \mathscr{P}(\omega_1)$, that is, a belief such that the expected individual scale effect is equal to the socially optimal one at ω_1. In other words, there must exist *some* belief (not necessarily one induced at equilibrium) such that $\omega < \omega_1$ leads to underprovision, $\omega > \omega_1$ to overprovision and that for $\omega = \omega_1$ the socially optimal actions and the equilibrium ones coincide. On the contrary, if we take a ω_1 such that $\mathscr{P}(\omega_1) = \varnothing$, it is easy to show that at ω_1 all beliefs p lead to overprovision and that $\tilde{v}(x;\omega_1)$ is strictly increasing in x.[14] That is, the absence of the possibility of underprovision makes the expert at ω_1 strictly benefit from inducing more *pessimistic beliefs* and therefore destroys the credibility of any message.

We now identify key properties and limitations of informative communication in our setting. First, we provide a sufficient condition on the fundamentals of the environment –population size, agents' prior expectations, and scale effect—that leads to complete communication failure. Second, we demonstrate that even when informative equilibria may exist, their informativeness about high states of the world weakly deteriorates as the number of agents increases or as prior expectations decline. Finally, we provide a sufficient condition for existence of 2-partition informative equilibria.

We first establish a sufficient condition such that only uninformative communication equilibria exist. The following result relies on two mild assumptions: (A_1) the probability distribution of the prior belief has an increasing hazard rate and that (A_2) φ is log concave.[15,16] We later show (Theorem 2) that one can dispense with these conditions at the cost of a less tight sufficient condition while preserving our main interpretations.

Theorem 1. *Assume that (A_1) and (A_2) hold. Then there exists no informative communication equilibrium whenever*

$$\mathbb{E}_{p_0}[\varphi(\tilde{\omega})] \leq n\varphi(a). \tag{6}$$

[14]Assume instead that $\mathscr{P}(\omega_1) = \varnothing$ *and* that there exists some p' such that $\mathbb{E}_{p'}[\varphi(\tilde{\omega})] > n\varphi(\omega_1)$. As there always exists a p'' such that $\mathbb{E}_{p''}[\varphi(\tilde{\omega})] = \varphi(a) < n\varphi(\omega_1)$, we can define $p := \alpha p' + (1-\alpha)p''$ such that $\mathbb{E}_p[\varphi(\tilde{\omega})] = n\varphi(\omega_1)$ for some $\alpha \in (0,1)$, contradicting the assumption that $\mathscr{P}(\omega_1) = \varnothing$.

[15]Formally, (A_1) requires that the prior belief p_0 is such that the ratio $\frac{p_0(\omega)}{1-\int_a^\omega p_0(y)dy}$ is increasing in ω. This property holds for many commonly-used probability distributions such as uniform, normal or exponential distributions. See Bagnoli and Bergstrom (2005) for a detailed list.

[16]Condition (A_2) is equivalent to φ'/φ is decreasing for all $\omega \in \Omega$. It is immediately satisfied when φ is concave (or linear) and holds for some convex function as well.

While only sufficient, condition (6) identifies critical boundaries on the population size, the level of prior expectations, and the curvature of the scale function beyond which communication becomes impossible.[17] We summarize the relevant comparative statics as follows.

Corollary 1. *At any (n, p_0, φ), the expression $\mathbb{E}_{p_0}[\varphi(\tilde{\omega})] - n\varphi(a)$ is strictly decreasing in n and strictly decreasing for priors p_0 that lower $\mathbb{E}_{p_0}[\varphi(\tilde{\omega})]$. Furthermore, if φ is concave and condition (6) holds at (n, p_0, φ), then it also holds for any scale function obtained as a concave nondecreasing and nonnegative transformation of φ.*

In other words, this means that condition (6) and Corollary 1 define a set of critical public bad problems $\mathscr{C} := \{(n, p_0, \varphi) \mid \mathbb{E}_{p_0}[\varphi(\tilde{\omega})] = n\varphi(a)\}$ such that any other public bad problem with either a larger population, lower prior expectations, or a more concave loss function that those in $\mathscr{C}$ also satisfies condition (6) and therefore exhibits complete communication failure.

Conversely, even if a public bad problem (n, p_0, φ) violates condition (6), Corollary 1 ensures that there always exists a sufficiently large increase in population size or a sufficiently large decrease in prior expectations that will eventually cause it to be satisfied.

Although condition (6) identifies only a rather coarse set of public bad problems in which communication entirely fails, it nonetheless provides meaningful critical and well-behaved boundaries on (n, p_0, φ). Furthermore this condition is independent of other features of a public bad problem such as the private benefit or the damage functions as it relies only on a comparison between the private expected marginal damage and the social lowest marginal damage. The existence of a critical bound on population size for any public bad problem is particularly relevant in the case of large-scale public bad problems related to climate change or to public health that generally involve a large number of players.

Intuitively, condition (6) identifies situations in which a large population size or a low expectation of the scale effect drive the social cost far away from the individual one. As a result, the misalignment between each contributor and the utilitarian expert is large enough to undermine the expert's credibility. In other words, each agent becomes dubious about the publicly disclosed information as they know that the expert faces a much larger cost than theirs and is therefore tempted to provide excessively pessimistic information only.

Finally, it is worth stressing that these communication failures occur in a fully symmetric environment. All agents share the same objectives, the same prior belief, and respond equally to the public information. Therefore, the only source of disagreement is through the perception of externalities between the agents and the expert and not because of the diversity of interests among agents.

Beyond the threshold cases characterized by Theorem 1 and Corollary 1 establishing the existence of informative communication equilibria and their characterization with respect to our parameters of interests is sensibly more difficult. In particular, if communication fails at (n, p_0, φ) although condition (6) is not satisfied, we cannot conclude anything about the

[17] We emphasise that Theorem 1 does not restrict to 2-partition equilibria — the absence of informative communication equilibrium when condition (6) is satisfied is equivalent to saying that no K-partition equilibrium with $K \geq 2$ exists.

existence of communication at $(n+1, p_0, \varphi)$ (unless (6) is satisfied at $n+1$). Whether the stronger monotonicity property holds in general—namely, that communication failure at n implies communication failure at $n+1$ for any (p_0, φ)—remains an open question.

We can, however, provide some characterization results on the 'coarseness' of information provision – should it occur – with respect to the state of the world and say more about how communication quality evolves in environments that support some information transmission. Formally, let $\overline{\omega} \in \Omega$ define the supremum of states of the world that can serve as a cutoff point in any K-partition equilibrium for a given problem (n, p_0, φ). That is, if there exists any K-partition informative equilibrium, the threshold $\overline{\omega}$ is such that $\omega_{K-1} < \overline{\omega}$.[18] We obtain the following.

Proposition 3. *Assume conditions (A_1) and (A_2) are satisfied but not condition (6). Let $\overline{\Omega} = [a, \overline{\omega})$ denote the set of admissible states of the world that can serve as cutoffs in any K-partition informative equilibrium. It follows that $\overline{\omega}$ is strictly decreasing in n and decreasing for a shift from a prior p_0 to a prior $\tilde{p}_0$ where p_0 first-order stochastically dominates $\tilde{p}_0$. Moreover, $\overline{\omega} \leq a$ when condition (6) is satisfied.*

Proposition 3 establishes that the expert progressively loses the ability to communicate precisely about high states of the world as the population size increases or as the prior shifts probability mass from high states to low states. In other words, information transmission about the high states of world becomes weakly 'coarser' as the public bad problem worsen. To illustrate what we mean by that, define $\overline{\Omega}_{[n]} := [a, \overline{\omega}_{[n]})$ the set of admissible states of the world and let $\omega_{[n]}$ denote the highest cutoff point of a K-partition equilibrium when the population is of size n.[19] It is immediate from Proposition 3 that $[a, \overline{\omega}_{[n+1]}) \subset [a, \overline{\omega}_{[n]})$ so that the set of admissible cutoffs for any remaining remaining equilibrium at $n+k > n$ shrinks from the right. Of course, it does not rule out the possibility that for some n we have that $\omega_{[n]} < \omega_{[n+1]}$, that is, there is some *local improvement* in terms of information transmission for high states of the world. But as n increases, any such *local improvement* occur for equilibrium cutoffs points that are more and more concentrated in the region of the low states of the world.

To make our point even clearer, assume that there exist K-partition equilibria for all $n \leq \overline{n}$, where $\overline{n}$ defines the population threshold after which condition (6) is satisfied. Further assume that $\omega_{[2]} < \omega_{[3]} < \cdots < \omega_{[\overline{n}-1]}$, that is, information becomes more and more precise for high states of the world as $n < \overline{n}-1$ increases which seems to contradict our interpretation of coarseness of the information for high states. Proposition 3, however, implies that $\omega_{[\overline{n}-k]} < \overline{\omega}_{[\overline{n}-1]}$ for all $k = 1, \ldots, n-2$, i.e. that all equilibrium cutoffs points at any $n-k$ must lie below $\overline{\omega}_{[\overline{n}-1]} = \min_k \overline{\omega}_{[\overline{n}-k]}$. Hence, the sequence of equilibria is indeed becoming more informative about high states of the world but all of them are confined in a small region of the state space $[a, \overline{\omega}_{[\overline{n}-1]}]$ whose upper bound is defined by the coarseness boundary of a problem with $\overline{n}-1$

[18] Where recall that ω_{K-1} is the highest *nontrivial* cutoff point in a K-partition equilibrium as $\omega_K = b$ by convention.

[19] Note that we consider a sequence of highest equilibrium cutoff points of K-partition equilibria with respect to n only for simplicity of the exposition. The same logic applies to any sequence of highest equilibrium cutoff points of any K_n-partition equilibria with $K_n \in \{2, 3, \ldots\}$ being allowed to vary itself with n.

agents. In other words, it means that a *local improvement* from n to $n+1$ occurs precisely when information coarseness was already highly constraining the informative equilibrium in n.

Together, Theorem 1 and Proposition 3 demonstrate that larger populations and shifts to more *pessimistic* prior beliefs undermine expert credibility, either eliminating communication entirely or restricting it to progressively less informative ranges for the high states of the world. The fundamental mechanism is identical in both cases: the widening gap between individual and social incentives harms credibility, with the only difference being whether the misalignment is severe enough to prevent all communication or merely degrades its quality for high states.

We conclude by identifying a condition for which communication is guaranteed to succeed, completing our characterization.

Proposition 4. *Assume conditions (A_1) and (A_2) are satisfied and that $\tilde{v}(\varphi(a),a) > \tilde{v}(\mathbb{E}_{p_0}[\varphi(\tilde{\omega})],a)$ holds for a given problem (n, p_0, φ). Then there exists a 2-partition informative equilibrium at this (n, p_0, φ).*

The inequality condition of Proposition 4 requires that in the most favourable state $\omega = a$, the expert prefers full revelation to complete pooling, i.e., the expert at type $\omega = a$ would rather have agents overcontribute in response to full information than undercontribute based solely on their prior beliefs.[20] This condition is most likely satisfied when prior expectations are relatively high or when the number of agents is relatively low. However, it is difficult to provide monotonicity results with respect to the population size or prior expectations for condition $\tilde{v}(\varphi(a),a) > \tilde{v}(\mathbb{E}_{p_0}[\varphi(\tilde{\omega})],a)$ without strong assumptions on the defining features of the environment (private benefit, damage function). The major challenge resides in the countervailing effects induce by the contribution game on the expert's utility. For instance, an increase in population size not only increases the gap between the individual private marginal damage and the social one but also disciplines each agent to lower their contribution at equilibrium. The net effect on the expert's utility is ambiguous and deriving monotonicity results on the existence of communication is not possible.

Asymmetric agents— Consider now the case of asymmetric agents in which asymmetry is of the form $\varphi_i(\omega) := \gamma_i \phi(\omega)$, where $\gamma_i \in \mathbb{R}_+$ and ϕ is increasing in ω. The main difference with the symmetric case is that asymmetric agents respond differently to the same posterior belief p. We further assume that, for each agent, belief p induces a lower level of equilibrium action than belief p' whenever $\mathbb{E}_p[\varphi(\omega)] \geq \mathbb{E}_{p'}[\varphi(\omega)]$. This simply ensures that all agents' contributions decrease when they receive more pessimistic information.[21]

Applying a similar reasoning to that of the symmetric environment, we find that our main intuitions remain valid in this asymmetric environment.

[20]Notice that $\tilde{v}(\varphi(a),a) > \tilde{v}(\mathbb{E}_{p_0}[\varphi(\tilde{\omega})],a)$ implies $\mathbb{E}_{p_0}[\varphi(\tilde{\omega})] > n\varphi(a)$ as a consequence of Lemma 1 so that agents are over pessimistic under their prior belief.

[21]This condition is satisfied in the application of Section 4.

Theorem 2. *Assume $\varphi_i(\omega) := \gamma_i \phi(\omega)$, where $\gamma_i \in \mathbb{R}_+$ and ϕ is increasing. For any prior belief $p_0 \in \Delta(\Omega)$, there exists no informative communication equilibrium whenever*

$$\frac{\sum_{j \in N} \gamma_j}{\max_{j \in N} \gamma_j} \geq \frac{\phi(b)}{\phi(a)}. \tag{7}$$

Equation (7) pins down a sufficient condition for communication failures that relies only on the agent that suffers the most from the externalities. Communication is therefore more likely to fail when $\max_{j \in N} \gamma_j$ is low, in a similar spirit as in the symmetric case. When the number of agents increases, $\sum_{j \in N} \gamma_j$ must increase as well so that communication is also more likely to fail, consistently with our previous observations. Similarly, a low individual impact of externalities – evaluated by the ratio $\phi(b)/\phi(a)$ – increases the likelihood of communication failures.

Notice that when $\gamma_i = \gamma$ for all $i \in N$, condition (7) can be rewritten as $n \geq \varphi(b)/\varphi(a)$. This condition is a sufficient condition for communication failures in the symmetric case. In accordance with our previous observations, it shows that a large number of agents or a low individual impact of externalities – evaluated by the ratio $\varphi(b)/\varphi(a)$ – can each be responsible for communication failures. It shows that these intuitions hold for any increasing φ and any prior belief and even in the absence of (A_1) and (A_2). However, we say that condition $n \geq \varphi(b)/\varphi(a)$ is less tight than condition (6) in the sense that when (A_1) and (A_2) hold, it implies (6) and thus Theorem 1.

4. Non-Utilitarian Experts

In the following section we go beyond the assumption that the expert is utilitarian and consider side-taking experts: the ex post utility of the expert is aligned only with the one of some of the agents. We will consider two groups of agents: one with high exposure to social damage and one with low exposure. In our climate example, these groups could represent respectively the Global South, more exposed to climate change, and the less exposed Global North. An expert that sides with the highly exposed Global South would then have preferences corresponding to the Rawlsian standard. Conversely, an expert siding with the less exposed Global North would have opposite preferences to the Rawlsian standard, hereafter designated as anti-Rawlsian for simplicity.

Agents— We rely on the functional form defined by equation (1) and set $\phi(\omega) = \omega$ so that

$$u_i(e_i, e_{-i}; \omega) = \left(e_i - \frac{e_i^2}{2}\right) - \gamma_i \omega \frac{1}{2} \left(\sum_{j \in N} e_j\right)^2.$$

We further assume that the population of agents is divided into two groups, L and H, of the same size but with a different sensibility to the damage.[22] Agents in group L are such that $\gamma_i = \alpha M$ and those in group H such that $\gamma_i = (1-\alpha)M$. The parameter $\alpha \in (0, \frac{1}{2}]$ controls the degree of asymmetry between the two groups while $M \in \mathbb{R}_+$ controls the absolute magnitude of the individual scale effect. As $\alpha \leq \frac{1}{2}$, agents in group L – where L stands for *low* – face a lower impact of the damage than those in group H. The special case $\alpha = \frac{1}{2}$ corresponds to the symmetric setting. We divide the two groups in such a way so that regardless of the degree of asymmetry between them, the social scale effect is constant and equals to $\frac{n}{2}M$.[23]

For convenience, we let $u_L(e;\omega)$ and $u_H(e;\omega)$ denote the ex post utilities of agents in group L and in group H, respectively.

Expert— We now consider that the expert has a type $j \in \{U, R, AR\}$, which is common knowledge to all agents. Type U is identical to the utilitarian expert we have considered so far. Types R and AR are respectively the *Rawlsian* and the *anti-Rawlsian* experts. Formally, the utility of each type of expert, $v_j(e;\omega)$, is given by (omitting the arguments for convenience):

$$v_U := \frac{n}{2}(u_L + u_H), \quad v_R := \frac{n}{2}u_H, \quad v_{AR} := \frac{n}{2}u_L.$$

That is, the side-taking experts R and AR maximise the welfare of group H and group L, respectively. In other words, type R (resp. AR) is interested in the group that is the most (resp. least) exposed to the damage.

Notice that despite the fact that types R and AR side with one group of agents, there is still a conflict of interest between them and their respective group as the externality problem persists within a group.[24] Furthermore, type R (AR) is still *indirectly* interested in group L (H) as this group's level of actions affects group H (L) *via* the externalities.

We investigate the equilibrium cutoff value of a 2-partition communication equilibrium for each type $j \in \{U, R, AR\}$ of expert. Formally, we are interested in the value $\omega_j^* \in \Omega$, if it exists, that solves $v_j(e(p^-);\omega_j^*) = v_j(e(p^+);\omega_j^*)$ where $p^-(\omega) = p_0(\omega|\omega \geq \omega_j^*)$ and $p^+(\omega) = p_0(\omega|\omega < \omega_j^*)$ are the posterior beliefs induced on each side of the cutoff ω_j^*. When such a cutoff exists in the interior of Ω, it characterizes a 2-partition informative equilibrium.

Proposition 5. *Fix the parameters (Ω, N, α, M) of the game. If a 2-partition informative equilibrium exists when the expert is anti-Rawlsian, then such an equilibrium also exists when the expert is Utilitarian. Similarly, if such an equilibrium exists when the expert is Utilitarian, then it also exists when the expert is Rawlsian. Moreover, when these cutoffs exist, they are unique and satisfy $\omega_{AR}^* < \omega_U^* < \omega_R^*$.*

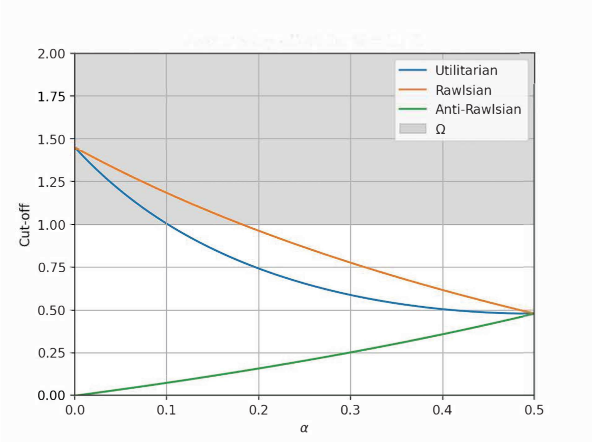
While we can analytically characterize the conditions under which these cutoffs exist, the resulting expressions are not tractable in closed form. To illustrate the effect of the expert's

[22]Formally, let $L \subset N$ and $H \subset N$ denote these two groups where $|L| = |H| = \frac{n}{2}$, where n is assumed to be even, for simplicity. This last assumption could easily be relaxed without changing our main results.

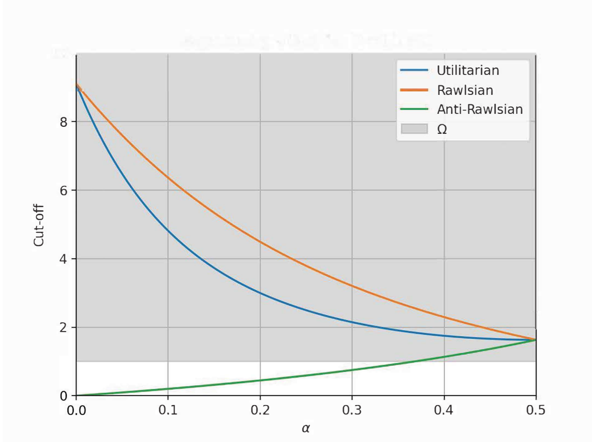
[23]Indeed, $\sum_{i \in N} \gamma_i = \frac{n}{2}\alpha M + \frac{n}{2}(1-\alpha)M = \frac{n}{2}M$.

[24]We call group a set of agents of cardinal at least 2.

normative orientation on communication, we compute these cutoffs numerically and plot them in Figure 2.



(a) Limited uncertainty: $\Omega = [1, 2]$.



(b) Large uncertainty: $\Omega = [1, 50]$.

Figure 2: The effect of heterogeneity on cutoff types.

Figure 2a plots the theoretical values of the cutoff state for a one cutoff equilibrium of the game for the three potential sender types, when uncertainty is small ($\Omega = [1, 2]$). Notice that the cutoff type is only defined when it is in (a, b), that is, in the grey area. Figure 2b does the same for larger uncertainty ($\Omega = [1, 50]$). This shows that the ordering given by condition (5) does translate to the existence of an informative equilibrium. Information transmission is the easiest for the Rawlsian, then for the utilitarian and finally for the anti-Rawlsian. One can see that asymmetry helps communication for the utilitarian and the Rawlsian but not for the anti-Rawlsian.

To understand this pattern, consider the case of the Rawlsian expert. The more asymmetry there is, the less the most exposed agent (type L) faces potential damages, making his action less sensitive to information. To the contrary, the more asymmetry there is, the more the most exposed agent's (type H) action matters for the expert, as the potential damage he faces increases. So, the more asymmetry there is, the more the payoff of the expert will depend on the more exposed agents' action. Yet, as, by definition, the expert has the same ex post utility as type H, an increase in asymmetry effectively reduces the communication bias. Asymmetry in the anti-Rawlsian case has the opposite effect, as the expert has the same ex post utility as the less exposed agent L, effectively increasing the communication bias. The utilitarian case sits naturally between the two former ones, as the expert's objective is an average between both agents' utility. Therefore, increasing the number of type L agents would, for instance, naturally drag the utilitarian curve in the direction of the anti-Rawlsian one, as the objective of such an expert would be always further away from the more exposed type H.

We find the results of our analysis relevant for our main climate example. It appears that from an informational perspective, an expert aligned with the preferences of the most exposed agents, such as the Global South in our climate example, will do better in conveying scientific evidence than an expert aligned with the preferences of the Global North. It appears that the latter case corresponds much more, for instance, to the current composition of the IPCC (Ho-Lem, Zerriffi and Kandlikar, 2011), adding another layer of explanation to the failure in raising appropriate climate risk awareness.

5. Credible Communication and Welfare Improvement

In this section, we will explore the connection between value of information[25] and the strategic credibility of the expert. First, we will argue that communication failure is not solely caused by negative value of information. There are cases where information provision would be welfare improving for the expert, but the strategic setting makes any of her claims non-credible. Second, we show that, for the expert, there can be a trade-off between informational and welfarist goals. In an environment with externalities, there are cases where the expert can provide information in a strategically credible way through cheap-talk, but would not ex ante benefit from it. These cases contrast with the linear-quadratic example of Crawford and Sobel (1982) mostly used in applications where, if an informative equilibrium exists, it is welfare improving for the sender. We show that in the case of public good games, the intuition of the linear-quadratic example does not survive.

To this end, we make use of *Bayesian persuasion* techniques (Kamenica and Gentzkow, 2011), so as to abstract away from strategic constraints, retaining only informational ones.[26] In considering this more general form of information provision, this section extends some of the results of Bramoullé and Treich (2009) and Asheim (2010), who have shown that disclosure of hard information in public good games is not always beneficial to the expert.[27]

Following Kamenica and Gentzkow (2011), define S to be the space of the realisations of a signal and let $s \in S$ denote an element of this set. The expert can choose a signal π that consists of a family of distributions $\{\pi(\cdot \mid \omega)\}_{\omega\in\Omega}$ over S.[28] The expert chooses the signal π which maximises their expected utility. The choice of signal π and its realisation $s \in S$ are perfectly observed by each agent $i \in N$ before they choose their action level.

As it is standard in these environments, it is useful to notice that any signal π that induces the same posterior belief $p \in \Delta(\Omega)$ has the same value for the expert as it induces the same level of actions of the agents. Hence, we can write the expected utility of the expert directly as a function of the induced posterior belief p as follows:

$$\hat{v}(p) = \mathbb{E}_p[v(e(p), \omega)]. \tag{8}$$

[25]Here, we measure value of information through the expected welfare of the expert, for a given informative signal.

[26]Bayesian persuasion assumes that the expert can commit to displaying the results of a known statistical experiment. Therefore, incentive constraints on the credibility of these results are lifted, which only have to satisfy Bayes plausibility (Kamenica and Gentzkow (2011) p.2594).

[27]Information disclosure with hard information is a degenerate case of information design where only perfectly informative or uninformative experiments are allowed.

[28]For instance, when Ω and S are finite spaces, the expert can choose any function $\pi : S \times \Omega \to [0, 1]$ such that $\sum_{s\in S} \pi(s \mid \omega) = 1$ for all $\omega \in \Omega$.

We now analyse whether the expert can benefit from communication or if they are better off choosing an uninformative signal. We rely on one of the very powerful characterisation results of Kamenica and Gentzkow (2011) that states that the expert cannot benefit from communication as soon as their expected utility function, as defined by (8), is concave in p.[29]

Theorem 3. *Assume that for all $i \in N$, $u_i(\cdot)$ is defined by equation (1) with $\gamma_i = \gamma \in \mathbb{R}_+$ and $\phi(\omega) = \omega$, then the expert does not benefit from communication with commitment power whenever $\gamma \geq \frac{2n-1}{an(n-2)}$.*

The condition given by Theorem 3 simply ensures the concavity of the utility function of the expert $\hat{v}(p)$ in p and therefore provides necessary and sufficient condition on the parameters of the game for the expert not to benefit from communication even with the ability to commit to a signal structure. Notice that Theorem 3 makes no assumption on the agent's prior belief $p_0 \in \Delta(\Omega)$.

Let us call n_C the largest number of agents for which credible communication is possible[30] and n_{BP} the largest number of agents for which communication is welfare improving.[31] Four cases are possible:

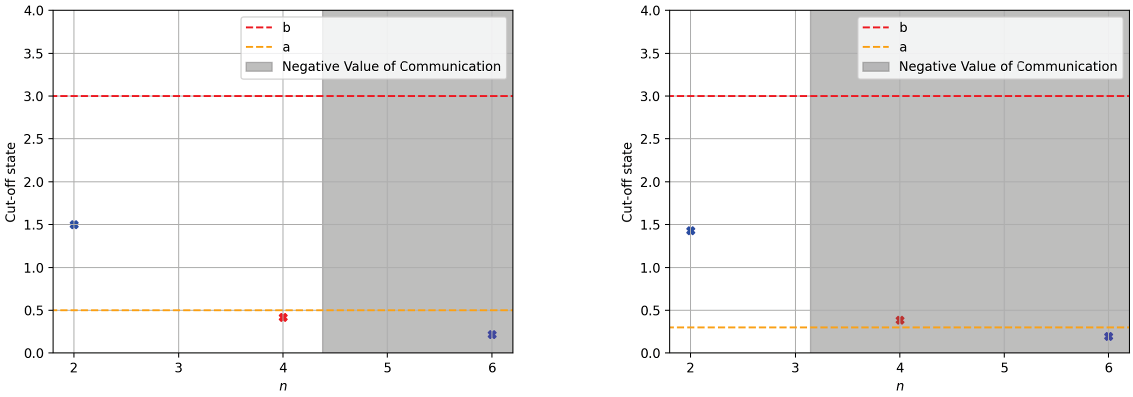
	Credible	Not credible
Welfare improving	$n < \min\{n_{BP}, n_C\}$ (i)	$n_C < n < n_{BP}$ (ii)
Not welfare improving	$n_{BP} < n < n_C$ (iii)	$\max\{n_C, n_{BP}\} < n$ (iv)

As mentioned at the beginning of this section, it is tempting to believe that only cases (i) and (iv) can occur in our game: either information is not welfare improving and communication is impossible or information is welfare improving and communication is possible. This is actually not the case. Consider the linear-quadratic example of Crawford and Sobel (1982): cases (i), (ii) and (iv) can already happen. The most informative equilibrium is both welfare improving for the sender and credible (case (i)). Truthfully communicating the state would be even better in terms of welfare, but not credible (case (ii)). Always saying that the state is the most catastrophic (b) is both non-credible and non-welfare improving (case (iv)). Case (iii) however cannot happen in the linear-quadratic example: the sender always has an ex-ante preference for being as informative as possible. It is the main contribution of Bramoullé and Treich (2009) to show that in a public bad game with uncertainty, if an informed sender can certify the state, there are cases where it is not welfare improving to do so. Case (iii) parallels this result and shows it extends to a sender with non-certifiable information that has to comply with a credibility constraint. Although we managed to derive an analytical value for these cases, their expression is untractable, as often when one leaves the realm of linear-quadratic models. Therefore we provide numerical examples of these cases in Figure 3.

[29] See Corollaries 1 and 2, and Remark 1 in Kamenica and Gentzkow (2011).

[30] Call $\omega_1(n)$ the cutoff state in the one cutoff equilibrium as a function of n (if it exists) between a utilitarian expert and the agents. Formally n_C is defined such that $\omega_1(n_C) > a$ and $\omega_1(n_C + 1) < a$.

[31] We derive this value directly from Theorem 3 to obtain $n_{BP} = \frac{1+aM+\sqrt{(aM)^2+aM+1}}{aM}$.



(a) Welfare improving non-credible communication for $\Omega = [0.5, 3]$, $\alpha = 0.1$ and $M = 1.5$.

(b) Non-welfare improving credible communication for $\Omega = [0.3, 3]$, $\alpha = 0.1$ and $M = 5$.

Figure 3: Dichotomies between Credible Communication and Welfare Improvement.

Figure 3 displays the value of the cutoff state in a one cutoff equilibrium—if it exists—in function of number of agents (n) and fixed values of the other parameters. For this cutoff to exist, its value must be in the support of the prior ($[a, b]$), that is, between the dotted lines. The shaded area stems from Theorem 3 and gives the values of n for which information transmission is not beneficial for the expert ($n \geq n_{BP}$). Figure 3a corresponds to case (ii). When $n = 2$, communication is credible and information can be payoff improving. When $n = 4$, it is not credible anymore, but information provision through Bayesian persuasion would be welfare improving. Only when $n = 6$ is communication not credible nor payoff improving. This is a clear case where communication failure is not due to the absence of value of information but to strategic constraints that affect the expert's credibility.

Figure 3b corresponds to case (iii). When $n = 2$, communication is credible and payoff improving. When $n = 4$, it is still credible, but not payoff improving anymore, and when $n = 6$ communication is not credible nor payoff improving. We find these cases remarkable, because they depict situations where two equilibria exist: one where information is credibly conveyed to the agents but is harmful for welfare and one where no information is conveyed. It follows that for the expert, choosing the equilibrium strategy corresponding to one or another of these equilibria is operating a real *arbitrage* between welfarist and epistemic objectives.

It could be argued that scientific deontology compels scientist at only conveying the current state of knowledge to their audience, regardless of their practical consequences. This paper, however, shows that this argument is fragile. Assuming that the expert accounts for welfarist considerations, at least alongside epistemic ones,[32], makes truthful communication non-credible.

[32]Say that the expert's utility can be separated in two components: a pragmatic and an epistemic one. The epistemic component only depends on the accuracy of the expert's claim and can be captured by $v_E(m, \omega) = -(m - \omega)^2$. The pragmatic component v_P is concerned with welfarist consideration such as those discussed so far (utilitarian, Rawlsian or anti-Rawlsian). Assuming that the expert's preferences is a mixture of both components, such that $v = \varepsilon \times v_E + (1 - \varepsilon) v_P$, with $\varepsilon \in [0, 1)$, will still lead to a difference between optimal actions between the expert and the outcome of the contribution game. Because v still exhibits the property of the sender's utility function in Crawford and Sobel (1982) one can show that full revelation is never an equilibrium strategy for the expert.

It seems much more likely to us, however, that scientific deontology's role in scientific communication is in the selection across the equilibria we described above; it will lead scientists to favour epistemic equilibria over welfarist ones.

6. Discussion

We studied the failure of communication regarding risks in the commons. We found that limited uncertainty regarding the damage, low marginal damage due to contributions and a high number of contributors can each be responsible for this failure of information transmission. We also considered experts with different objectives and found that Rawlsian preferences and high heterogeneity reduce the informational problem. Finally, we showed that communication failure is not solely caused by negative payoff returns from communication for the expert, as there are cases where credible communication is possible but not welfare improving. We now discuss the relevance and implications of these results.

6.1. Assumptions

Scientific communication— An important application for our model is the effect of scientific communication on public behaviour regarding the commons, for instance regarding GHG emissions and their long-term consequences for global warming. Of course, in this example as in others, counter-acting mechanisms that allow for some transmission of information are also at play. Scientific reputation effects, for instance, might play in favour of experts' credibility. Scientific communication is a complex phenomenon that cannot be summarised by a single model. Nevertheless, in order to better understand the specific effect we are interested in, we focused on the extreme case where scientific information is solely provided through non-certifiable communication. Arguably, this might have been the case in the late 1980s and early 1990s, following Hansen's landmark 1988 Senate testimony that brought climate change into mainstream public discourse and created widespread public perception of scientific consensus on the issue (Hansen, 1988, Besel, 2013). Yet, as argued by Weart (2008), climate effects remained invisible to direct public observation as scientists predicted warming effects would "*probably become evident around the year 2000*". The underlying evidence came from complex computer models and studies of ancient ice that showed synchronicity between temperatures and CO_2, information completely inaccessible to public verification. Moreover, scientific findings remained largely within academic circles, with climate science coverage appearing only "*deep on an inside page*" of newspapers (Weart, 2008), creating the non-certifiable information environment our model captures during this critical period when public awareness of expert consensus had emerged but verification mechanisms remained absent.

Single sender— In many instances, there is more than one expert communicating with the public on the state of science. Often, they are not perfectly informed and therefore they may disagree. The theoretical literature on multiple sender cheap-talk communication games provides mixed results. Battaglini (2002) and Battaglini et al. (2004) show that simultaneous communication generally lead to full revelation while Krishna and Morgan (2001) show that under sequential communication information transmission is still partial. Our model applies when the informed parties are perceived as sufficiently unified by the decision makers to be able to coordinate on their communication. An example of this coordination might be the IPCC and its communication on climate damages. As argued by Tol (2011), the IPCC's monopolistic situation on climate knowledge could enable this coordination. What this paper shows is that a strategic counterpart of this coordination is a likely failure in information transmission.

Non certifiable information— An important assumption in our paper is the one of absence of commitment power of the expert, including in a Kamenica and Gentzkow (2011) way. It might be interesting to compare our results to those existing under the assumption that the expert can perform information design. The literature on information design with one sender and multiple receivers is relatively thin. Some contributions encompass payoff externalities among receivers (Bergemann and Morris, 2019, Perego, 2023) but focus only on general characterisations of Bayes-correlated equilibria or duality methods rather than on results corresponding to the specific case of our model. Existing frameworks that explicitly do focus on multiple receivers typically abstract from public-good interactions by assuming either independent receivers or purely informational network links, as in Arieli and Babichenko (2019) on private Bayesian persuasion, Castiglioni and Gatti (2023) on public Bayesian persuasion, or Egorov and Sonin (2021) on persuasion on networks, all of which differ from our setting where receivers' actions generate a shared public bad. An exception is Caparrós and Vosooghi (2022), which is a natural counterpart to our model in the information-design approach. It analyses IPCC communication in a dynamic public-bad setting under the assumption that scientific assessments are verifiable and that the sender can commit ex ante to an information-disclosure rule. In their framework, the credibility problem is largely solved by construction: the IPCC chooses an optimal signal structure and full revelation of the damage parameter is typically optimal from both a welfare and a coalition-stability perspective, so that commitment and verifiability reconcile informational and welfarist objectives. By contrast, our model explicitly drops verifiability and commitment and instead treats climate communication as cheap talk from an expert who fully internalises the externality. Precisely in the large-scale public-bad environments that motivate both approaches, the resulting gap between individual and social damages makes upward distortion of risk systematically attractive for a utilitarian planner, and forward-looking agents therefore rationally discount her messages. Thus, Bayesian persuasion presumes exactly the commitment power and hard evidence that real-world climate experts often lack, whereas our cheap-talk analysis suggests that, in their absence, even well-intentioned experts may end up "*speaking into the wind*", with scientific deontology playing a role only in selecting among multiple equilibria when informational and welfarist goals diverge.

6.2. *Implications*

Values in Climate Science— One result we believe is worth pointing out is that Rawlsian preferences benefit communication, compared with utilitarian preferences, when there is asymmetry among the receivers. This result connects with the normative debate on what welfare criterion a social planner should adopt (Sen, 1976, Broome et al., 2008), in particular when aiming at regulating the commons. It shows that the utilitarian choice comes with an epistemic burden relative to the Rawlsian one: by internalising the full aggregate cost of the public bad, the utilitarian expert's normative objective diverges more sharply from each individual agent's self-interested perspective, making her communication less credible. This finding has direct implications for a broader debate in the philosophy of science on the role of normative choices in scientific assessments. A growing consensus holds that expert panels—including the IPCC—inevitably embed value judgments in their recommendations, through choices such as the social discount rate, the treatment of tail risks, or the weighting of present versus future generations (Douglas, 2008, Winsberg, 2012, Intemann, 2015, John, 2017). Our results suggest that these normative choices are not only a matter of fairness or accuracy—they have direct strategic consequences for the credibility of the expert's communication. In particular, an expert panel that adopts a utilitarian aggregation criterion will face a larger credibility deficit than one that adopts a more Rawlsian criterion focused on the most vulnerable. If one thinks of the climate change example, there is a clear asymmetry in damages at the scale of countries, and the question of which social criterion should be adopted has been widely debated (Fleurbaey and Zuber, 2017, Broome, 2017). Our model adds a communicative dimension to this debate: beyond its intrinsic normative merits, the choice of welfare criterion shapes the strategic conditions under which expert knowledge can be credibly transmitted. A Rawlsian expert panel, by focusing on the most exposed agents of the Global South, adopts a normative objective that is closer to the private interests of those most affected, and thereby achieves greater communicative credibility than a utilitarian one. This suggests that the composition and normative mandate of expert bodies such as the IPCC are not only a question of fairness, but also one of epistemic effectiveness.

Competing Explanations— The mechanism our model proposes—strategic credibility loss arising from the divergence between the expert's normative objective and agents' individual incentives—generates empirical predictions that distinguish it from competing explanations of communication failure such as limited attention (Mankiw and Reis, 2002), motivated reasoning (Bénabou and Tirole, 2016), or distrust rooted in perceived incompetence or institutional capture (Viscusi and Hamilton, 1999). First, our model predicts that the conditions under which communication failure arises become easier to satisfy as the number of contributors to the public bad increases, holding the quality and content of the expert's information constant. This is because a larger group size widens the gap between the individual cost each agent internalises and the aggregate social cost the expert seeks to correct, making it harder for the expert to be perceived as credible. Neither limited attention nor motivated reasoning generates this group-size prediction: comparing public trust in expert recommendations across settings that differ in the scale of the underlying collective action problem—for instance, global climate policy versus local pollution abatement—thus provides a natural way to isolate the mechanism empirically. Second, the mechanism is symmetric across political identities: even audiences normatively aligned with the expert should discount her messages when the public good structure is sufficiently large, whereas motivated reasoning predicts distrust concentrated among ideologically misaligned groups. Finally, and most directly, credibility in our model should respond to signals of *value alignment* more than to signals of competence or institutional independence. This is consistent with Lupia (2013)'s experimental finding that perceived commonality of interests dominates both partisan identification and expertise in determining whether audiences follow a speaker's advice, and with Mildenberger et al. (2022)'s field evidence that perceived interest alignment—rather than perceived competence—is the primary determinant of effective climate communication.

Policy Implications—What do we learn from our study about expert communication regarding risks in the commons? A first lesson is that experts communicating to a large number of agents contributing to a public bad are ineffective. This is the case in our lead example of GHG emissions and their long-term consequences for global warming, if directed at the general public. The same holds for the case of massive adoption of a vaccine relying on unprecedented technologies such as mRNA[33]. To the contrary, when addressing a small set of political decision-makers, our results suggest that information transmission might succeed. Regarding this aspect of communication failure, a solution might be to reduce the number of strategic agents by bunching contributors in a small number of groups. This could be done by the use of coalitions with internal transfers, in the manner suggested by the climate club literature (Nordhaus, 2015, Weischer, Morgan and Patel, 2012). A second, somewhat unexpected implication of our paper is that recognising the magnitude of the uncertainty faced by society actually favours expert communication's effectiveness. In the GHG emissions example, this could be done by acknowledging the scientific uncertainties regarding possible climate futures. A third implication of our model is that raising awareness of the severity of the individual scale effects agents will potentially face also plays in favour of communication. In our GHG emissions example, this could be done by bringing attention to the non-linearity of climate damages, for instance because of potential climate tipping points.

6.3. Other Applications

Central Bank Communication in Banking Markets—Central banks routinely communicate about economic conditions to multiple banks whose investment and lending decisions create spillover effects on each other. Consider a setting where the central bank observes aggregate economic productivity but individual banks remain uncertain about both the economic state and other banks' likely responses to central bank communications. Banks must decide how much

[33]This is line with Everett et al. (2021) who argue that because the COVID-19 crisis was such an unexpected event, compliance with health recommendations has mostly been determined by the degree of trust populations have in their leaders.

to invest in long-term productive projects versus holding liquid reserves. The profitability of each bank's investments depends not only on the underlying economic conditions but also on the aggregate level of investment across all banks. When more banks invest, this creates positive spillovers through deeper capital markets, improved infrastructure, or enhanced network effects that benefit all participating banks. However, individual banks making investment decisions do not fully account for these positive externalities they generate for others. The central bank aims to promote overall economic welfare by encouraging efficient investment levels. When productivity is high, the central bank would like banks to invest more aggressively to capitalise on favourable conditions and generate beneficial spillovers. When productivity is low, the central bank prefers more conservative investment to avoid systemic risks. However, this creates a fundamental credibility problem for central bank communication.

If banks believed the central bank would always communicate truthfully, the central bank would face strong temptations to occasionally exaggerate positive economic conditions to encourage more investment and capture the beneficial spillovers, or to overstate negative conditions when it perceives excessive risk-taking. Banks, anticipating this incentive to manipulate their behaviour, cannot fully trust central bank communications even when the central bank would prefer to be truthful. This credibility problem prevents the central bank from fully revealing its private information about economic conditions. Instead, communication equilibria emerge where the central bank can only credibly communicate crude signals about whether conditions are broadly "favourable" or "unfavourable" rather than providing precise economic forecasts. The equilibrium level of information transmission is insufficient from the central bank's perspective—it would prefer to communicate more detailed information than banks are willing to believe. Applied research shows that these are some of the practical challenges faced by central bank in their communication (Blinder et al., 2024). Central banks themselves recognize that they must communicate simultaneously with financial market participants, government officials, and the general public, each with different interests and expertise levels, creating a "cacophony problem" (Cecchetti and Schoenholtz, 2019, Casiraghi, 2022).

Public Health Communication During Pandemic Response—Another example are health agencies when addressing vaccination decisions. Public health authorities possess complex information about disease transmission patterns and vaccine effectiveness that, just like in the climate case, can be assumed to be private information. Vaccination is a public good: high vaccination rates reduce disease circulation, creating protective benefits for immunocompromised individuals who cannot safely receive vaccines and decreasing the probability that vaccine-resistant variants will emerge. Citizens make their decision regarding vaccination under uncertainty about their personal and the social health risks. It is reasonable to assume health authorities seek to maximize population welfare by promoting vaccination levels that account for these spillover effects. During periods of high vaccine effectiveness and low adverse event rates, authorities benefit when citizens adopt vaccination widely to establish herd immunity. Conversely, when safety signals emerge or vaccine effectiveness diminishes against new variants, authorities may prefer more selective vaccination strategies targeting high-risk populations. These shifting preferences create inherent tensions in health authority communication strategies.

Again, we are facing a cheap talk problem for health authorities. Citizens know that authorities have incentives to emphasize vaccine benefits when seeking higher uptake to capture positive spillovers, while potentially minimizing safety concerns when faced with excessive hesitancy that threatens public health goals. Anticipating this strategic behaviour, citizens discount official health communications even when authorities would genuinely prefer truthful disclosure. Experimental evidence supports this dynamic: Petersen et al. (2021) demonstrates that honest communication about negative vaccine characteristics reduces immediate acceptance, creating institutional pressures toward vague reassurances that paradoxically generate both short-term scepticism and lasting distrust. These credibility constraints force health authorities into suboptimal communication patterns. Rather than providing detailed, individualized risk-benefit assessments, authorities can only credibly offer broad categorical recommendations about vaccination suitability for general population groups. The resulting information transmission falls short of authorities' preferred level—they would choose to reveal more nuanced guidance than citizens find credible given the strategic context.

More generally, empirical evidence supports our claim that strategic considerations undermine health authority communication effectiveness and create fundamental credibility problems. Deiana et al. (2022) exploit the quasi-experimental suspension of AstraZeneca vaccines to demonstrate that citizens strategically interpret official health communications: the temporary suspension created persistent scepticism toward all vaccines even after safety reviews concluded and authorities resumed recommendations, indicating that citizens view health authority communications as potentially manipulative rather than purely informational. This strategic response pattern reflects citizens' rational expectation that authorities may overstate safety or understate risks to achieve public health objectives. Depetris-Chauvin and González (2024) provide quasi-experimental evidence that citizens' vaccination decisions respond more to political signals about authority trustworthiness than to objective health information, with eligibility rule changes creating differential uptake patterns that persist long after the policy interventions, suggesting that citizens make vaccination decisions based on their assessment of authority credibility rather than purely on health considerations.

7. Conclusion

The results of our paper question the effectiveness of public policies aimed at raising awareness regarding the tragedy of the commons, in the hope of mitigating its effects. Several strands of research have established correlations between public awareness regarding risks in the commons and engagement in their mitigation.[34] Yet, it is still a challenge for research to establish whether there is causation, and in which direction, between public awareness regarding risks in the commons and their mitigation. We showed that information provision does not, in general, cause a reduction in the externality problem. Instead, it is the externality problem that causes a failure

[34] See for instance Khatibi et al. (2021) for a systematic review in the case of climate change.

in information provision.

The failure of expert communication in public good contexts has long been recognised in literature and environmental discourse. Environmentalists refer to this phenomenon as the "Cassandra dilemma" (Atkisson, 1999)—the curse of making accurate predictions that systematically go unheeded. Similarly, Ibsen's *An Enemy of the People* (Ibsen, 1882) dramatises precisely the mechanism we model: a scientist who discovers threats to collective welfare faces public rejection when individual economic interests conflict with collective action on his truthful warnings.

Preferences and strategic interactions are at the root of the commons problem. To be effective, awareness raising policies may want to put more focus on shaping preferences towards a more sustainable standard. In our paper, we made the standard assumption that preferences over outcomes are information invariant. Relaxing this assumption in order to understand the formation and dynamics of preferences, in particular towards more altruistic ones, might be a first fruitful future avenue of research.[35] A second future avenue is on behavioural beliefs underlying equilibrium concepts: while the Nashian logic leads to the tragedy of the commons, other behavioural beliefs lead to collectively more desirable equilibrium concepts.[36] Triggering these behavioural beliefs or shifting preferences towards more cooperation might be more in the spirit of what awareness raising policies aim at achieving.

Appendix

Proof of Proposition 1. Let $(e_i(\omega), e_{-i}(\omega))$ denote the symmetric Nash equilibrium of the game played by the agents. The vector of equilibrium actions must solve, for all $i \in N$ and all $\omega \in \Omega$,

$$\frac{\partial B(e_i(\omega))}{\partial e_i} = \varphi(\omega)\frac{\partial D(e_i(\omega), e_{-i}(\omega))}{\partial e_i}$$

whereas the expert's first-best level of action must solve

$$\frac{\partial B(e_i^{FB}(\omega))}{\partial e_i} = \frac{\partial D(e_i^{FB}(\omega), e_{-i}^{FB}(\omega))}{\partial e_i} \sum_{j \in N} \varphi(\omega).$$

Assume that $e_i(\omega) \leq e_i^{FB}(\omega)$ for some $\omega \in \Omega$, then it follows that

$$\frac{\partial B(e_i(\omega))}{\partial e_i} \geq \frac{\partial B(e_i^{FB}(\omega))}{\partial e_i} = \frac{\partial D(e_i^{FB}(\omega), e_{-i}^{FB}(\omega))}{\partial e_i} \sum_{j \in N} \varphi(\omega) > \frac{\partial D(e_i^{FB}(\omega), e_{-i}^{FB}(\omega))}{\partial e_i} \varphi(\omega).$$

[35] Recent examples of such theories are Bernheim et al. (2021) or Boissonnet, Ghersengorin and Gleyze (2023).
[36] See Fourny (2020) for a systematic review.

As we have assumed that $\frac{\partial^2 D}{\partial e_i^2} > 0$ and $\frac{\partial^2 D}{\partial e_i \partial e_j} > 0$, it follows that if $e_i(\omega) \leq e_i^{FB}(\omega)$, then $\frac{\partial D(e_i^{FB}(\omega), e_{-i}^{FB}(\omega))}{\partial e_i} \geq \frac{\partial D(e_i(\omega), e_{-i}(\omega))}{\partial e_i}$. It immediately implies that

$$\frac{\partial B(e_i(\omega))}{\partial e_i} > \frac{\partial D(e_i(\omega), e_{-i}(\omega))}{\partial e_i} \varphi(\omega),$$

which contradicts the statement that $e_i(\omega)$ is a best-response to $e_{-i}(\omega)$. ■

Proof of Proposition 2. Take any two $(y, y') \in \Omega^2$ such that $y' \geq y$. Assume that $e = (e_1, \ldots, e_n)$ solves $\frac{\partial B(e_i)}{\partial e_i} = y \frac{\partial D(e_i, e_{-i})}{\partial e_i}$ and that $e' = (e'_1, \ldots, e'_n)$ solves $\frac{\partial B(e'_i)}{\partial e_i} = y' \frac{\partial D(e'_i, e'_{-i})}{\partial e_i}$. It follows that

$$\frac{\partial B(e_i)}{\partial e_i} - \frac{\partial B(e'_i)}{\partial e_i} = y \frac{\partial D(e_i, e_{-i})}{\partial e_i} - y' \frac{\partial D(e'_i, e'_{-i})}{\partial e_i}.$$

Assume that $e'_i > e_i$ for all $i \in N$. From the concavity of B, it follows that the left-hand side of the above equation is positive. From the convexity of D and the assumption that $\partial^2 D / \partial e_i \partial e_j > 0$ we must have that $\frac{\partial D(e'_i, e'_{-i})}{\partial e_i} > \frac{\partial D(e_i, e_{-i})}{\partial e_i}$. Hence the right-hand side is necessarily negative as $y' \geq y$ and we have a contradiction.

Hence, it must be that if $y' \geq y$ then $e'_i \leq e_i$ for all $i \in N$. To conclude the proof, notice that if we set y to $y(\omega) = \sum_{j \in N} \varphi(\omega)$ or to $y(p) = \mathbb{E}_p[\varphi(\omega)]$, it corresponds to equations (5) and (3), respectively. In the first case, take $\omega' \geq \omega$ so that $y(\omega') \geq y(\omega)$ which yields that $e_i^W(\omega') \leq e_i^W(\omega)$. In the second case, take p and p' such that $y(p') \geq y(p)$ and we obtain that $e_i(p') \leq e_i(p)$. ■

Proof of Lemma 1. For notational convenience, let $x := \mathbb{E}_p[\varphi(\tilde{\omega})] \in [\varphi(a), \varphi(b)]$ denote the agents' belief. Similarly, in a slight abuse of notation, let $e_i(x) := e_i(p)$. Hence, the expert's utility rewrites as

$$\tilde{v}(x, \omega) = n \left[B(e_i(x)) - \varphi(\omega) D(e_i(x), e_{-i}(x)) \right].$$

Taking the derivative with respect to x yields:

$$\tilde{v}_x(x, \omega) := n \left[\frac{\partial e_i(x)}{\partial x} \frac{\partial B}{\partial e_i}(e_i(x)) - \varphi(\omega) \sum_{j \in N} \frac{\partial e_j(x)}{\partial x} \frac{\partial D(e_i(x), e_{-i}(x))}{\partial e_j} \right].$$

For any $x \in [\varphi(a), \varphi(b)]$, and any two $i, j \in N$ we have that, omitting the arguments, $\frac{\partial e_i}{\partial x} = \frac{\partial e_j}{\partial x}$ and $\frac{\partial D}{\partial e_i} = \frac{\partial D}{\partial e_j}$, where the first equality stems from the symmetric equilibrium and the second from the symmetry of the damage function.

Notice that from the first-order condition of agent i's problem, equation (3), we have that at equilibrium

$$\begin{aligned}
& \frac{\partial B}{\partial e_i}(e_i(x)) - x\frac{\partial D(e_i(x),e_{-i}(x))}{\partial e_i} = 0 \\
\Leftrightarrow \quad & \frac{\partial B}{\partial e_i}(e_i(x)) - n\varphi(\omega)\frac{\partial D(e_i(x),e_{-i}(x))}{\partial e_i} = [x - n\varphi(\omega)]\frac{\partial D(e_i(x),e_{-i}(x))}{\partial e_i}.
\end{aligned}$$

Plugging the last expression into $\tilde{v}_x(x,\omega)$, we obtain

$$\tilde{v}_x(x,\omega) = n\frac{\partial e_i(x)}{\partial x}\frac{\partial D(e_i(x),e_{-i}(x))}{\partial e_i}[x - n\varphi(\omega)],$$

where $i \in N$ is arbitrary and irrelevant by symmetry. From Proposition 2 we have that $\frac{\partial e_i(x)}{\partial x} < 0$ and $\frac{\partial D(e_i(x),e_{-i}(x))}{\partial e_i} > 0$ by convexity of D. Hence, the sign of $\tilde{v}_x(x,\omega)$ depends only on the sign of $x - n\varphi(\omega)$.

It is easy to see that if $\mathscr{P}(\omega) = \varnothing$, then $x - n\varphi(\omega) < 0$ for all $x \in [\varphi(a),\varphi(b)]$ and $\tilde{v}_x(x,\omega) > 0$. It follows that $\tilde{v}$ is strictly increasing in x at ω and it is thus impossible to have $\tilde{v}(x,\omega) = \tilde{v}(x',\omega)$ for $(x,x') \in [\varphi(a),\varphi(b)]^2$ and $x \neq x'$. On the contrary, assume that $\mathscr{P}(\omega) \neq \varnothing$, then there exists a $x^* \in [\varphi(a),\varphi(b)]$ defined by $x^* = n\varphi(\omega)$, such that $\tilde{v}_x(x,\omega) > 0$ for all $x < x^*$ and $\tilde{v}_x(x,\omega) < 0$ for all $x > x^*$. Hence there exists $(x,x') \in [\varphi(a),\varphi(b)]^2$ where $x \neq x'$ such that $\tilde{v}(x,\omega) = \tilde{v}(x',\omega)$. ■

Proof of Theorem 1. Consider a candidate 2-partition communication equilibrium with cutoff point $\omega \in \Omega$. Let $\underline{X}(\omega) := \mathbb{E}[\varphi(\tilde{\omega}) \mid \tilde{\omega} \leq \omega]$ and $\overline{X}(\omega) := \mathbb{E}[\varphi(\tilde{\omega}) \mid \tilde{\omega} > \omega]$ denote the agents' beliefs on the left and on the right of the threshold ω, respectively. Notice that both $\underline{X}$ and $\overline{X}$ are increasing in ω, that their images are $\underline{X}(\omega) \in [\varphi(a), \mathbb{E}_{p_0}[\varphi(\tilde{\omega})]]$ and $\overline{X}(\omega) \in [\mathbb{E}_{p_0}[\varphi(\tilde{\omega})], \varphi(b)]$ and hence that $\underline{X}(\omega) \leq \overline{X}(\omega)$.

A necessary and sufficient condition for ω to be the cutoff point of a 2-partition communication equilibrium is that $\tilde{v}(\underline{X}(\omega),\omega) = \tilde{v}(\overline{X}(\omega),\omega)$. From Lemma 1, it is therefore necessary that $\underline{X}(\omega) < n\varphi(\omega) < \overline{X}(\omega)$. We now show that under the assumptions of Theorem 1 —i.e. (A_1), (A_2), and equation (6)— we have that $\overline{X}(\omega) \leq n\varphi(\omega)$ for all $\omega \in \Omega$. or equivalently, that there is no 2-partition communication equilibrium. Before proceeding with the rest of the proof, notice that if we were to consider a K-partition equilibrium with thresholds $(\omega_1,\ldots,\omega_{K-1}) \in \Omega^{K-1}$, then $\overline{X}(\omega_{K-1}) := \mathbb{E}[\varphi(\tilde{\omega}) \mid \tilde{\omega} > \omega_{K-1}]$ would be define in the exact same way as $\overline{X}$ in the case of a 2-partition equilibrium. As such, proving that $\overline{X}(\omega) \leq n\varphi(\omega)$ for all $\omega \in \Omega$ indeed proves that there is no K-partition informative equilibrium.

From the definition of $\overline{X}$, we can explicitly compute that

$$\overline{X}(\omega) = \frac{\int_\omega^b \varphi(y)p_0(y)dy}{\int_\omega^b p_0(y)dy} = \frac{\mathbb{E}_{p_0}[\varphi(\tilde{\omega})] - \int_a^\omega \varphi(y)p_0(y)dy}{\int_\omega^b p_0(y)dy}.$$

Therefore, proving that $\overline{X}(\omega) \leq n\varphi(\omega)$ for all $\omega \in \Omega$ is equivalent to show that for all $\omega \in \Omega$,

$$h(\omega) := \mathbb{E}_{p_0}[\varphi(\tilde{\omega})] - \int_a^{\omega} \varphi(y)p_0(y)dy - n\varphi(\omega)\int_{\omega}^{b} p_0(y)dy \leq 0.$$

It is immediate that $h(a) = \mathbb{E}_{p_0}[\varphi(\tilde{\omega})] - n\varphi(a) \leq 0$ holds from equation (6). It is also easy to see that $h(b) = 0$ also satisfies the above inequality. Furthermore, we have that

$$h'(\omega) = (n-1)\varphi(\omega)p_0(\omega) - n\varphi'(\omega)\int_{\omega}^{b} p_0(y)dy.$$

It follows that $h'(\omega) = 0$ implies that

$$\frac{p_0(\omega)}{\int_{\omega}^{b} p_0(y)dy} = \frac{n}{n-1}\frac{\varphi'(\omega)}{\varphi(\omega)}.$$

From (A_1) we have that the left-hand side of this equation is increasing in ω and from (A_2), the right-hand side is decreasing in ω. Hence, $h'(\omega) = 0$ has at most one solution in $\omega \in \Omega$.

Finally, notice that $h'(b) = (n-1)\varphi(b)p_0(b) > 0$. By continuity, it implies that there exists a $\hat{\omega} \in [a,b)$ such that $h'(\omega) > 0$ for all $\omega \in [\hat{\omega}, b]$. It follows that either (i) h is monotonically increasing on [a,b] so that $h(\omega) \leq h(b)$; or (ii) there exists a unique ω such that $h'(\omega) = 0$ but then this point must characterise a minimum or a saddle point of h so that $h(\omega) \leq h(b)$.

In both cases, we obtain that $h(\omega) \leq 0$ for all $\omega \in \Omega$ which is equivalent to say that there is no cutoff point $\omega \in \Omega$ that could satisfy the necessary and sufficient condition $\tilde{v}(\underline{X}(\omega), \omega) = \tilde{v}(\overline{X}(\omega), \omega)$ for a 2-partition communication equilibrium. Hence, no $K \geq 2$-partition communication equilibrium exists either and only the noninformative communication equilibrium exists. ■

Proof of Corollary 1. Consider a public good problem characterized by (n, p_0, φ). First, it is straightforward that $\mathbb{E}_{p_0}[\varphi(\tilde{\omega})] - n\varphi(a)$ is strictly decreasing in n as neither the prior expectation of the scale effect nor $\varphi(a) > 0$ vary in n. It is also immediate that any prior $\tilde{p}_0$ such that $\mathbb{E}_{\tilde{p}_0}[\varphi(\tilde{\omega})] < \mathbb{E}_{p_0}[\varphi(\tilde{\omega})]$ unambiguously strictly decreases the expression.

Assume now that φ is concave and take any function g that is concave, nondecreasing and nonnegative. Further assume that $\mathbb{E}_{p_0}[\varphi(\tilde{\omega})] \leq n\varphi(a)$ at (n, p_0, φ). Notice first that $g \circ \varphi$ is concave and therefore it is log concave, i.e. satisfies (A_2). Applying Jensen's inequality we have that $\mathbb{E}_{p_0}[g(\varphi(\tilde{\omega}))] \leq g(\mathbb{E}_{p_0}[\varphi(\tilde{\omega})])$ by concavity of g. As condition (6) holds and g is nondecreasing we immediately have that $g(\mathbb{E}_{p_0}[\varphi(\tilde{\omega})]) \leq g(n\varphi(a))$. Finally, as g is concave it is also subadditive, that is, $g(n\varphi(a)) \leq ng(\varphi(a))$. Hence it follows that $\mathbb{E}_{p_0}[g(\varphi(\tilde{\omega}))] \leq ng(\varphi(a))$, that is, condition (6) holds at $(n, p_0, g \circ \varphi)$. ■

Proof of Proposition 3. From Lemma 1 we know that the existence of a K-partition informative equilibrium requires that $\overline{X}(\omega) > n\varphi(\omega)$ for at least one $\omega \in \Omega$ where $\overline{X}(\omega)$ denotes the expectation of the scale effect conditional on being above the highest cutoff point. Similarly to the proof of Theorem 1, define

$$h_z(\omega) = \mathbb{E}_{p_0}[\varphi(\tilde{\omega})] - \int_a^{\omega} \varphi(y)p_0(y)dy - n\varphi(\omega)\int_{\omega}^{b} p_0(y)dy,$$

where the only difference is that we explicitly index the function by $z \in \{n, p_0\}$ to later account for changes in these parameters. Admissible cutoff points must satisfy $h_z(\omega) > 0$.

By assumption, we have that $h_z(a) = \mathbb{E}_{p_0}[\varphi(\tilde{\omega})] - n\varphi(a) > 0$. We also immediately have that $h_z(b) = 0$ and that $h_z'(b) > 0$. By the same continuity argument as in Theorem 1, there must exist a $\tilde{\omega} < b$ such that $h_z' > 0$ on the interval $(\tilde{\omega}, b]$ and thus that $h_z < 0$ on that same interval. Given that $h_z(a) > 0$ we cannot have $h_z' > 0$ on all $[a, \tilde{\omega}]$. It follows that $h'(\omega) = 0$ must have at least one solution in $[a, \tilde{\omega}]$. Recall that from the proof of Theorem 1 that (A_1) and (A_2) ensure that $h'(\omega) = 0$ has at most one solution.

Therefore, $h_z'(\omega) = 0$ has exactly one solution in $[a, \tilde{\omega}]$ that we conveniently define at $\tilde{\omega}$. It also implies that h_z is strictly decreasing over $[a, \tilde{\omega}]$ and that $h_z(\omega) = 0$ has a unique solution – excluding that in b as $\omega \in (\tilde{\omega}, b]$ is clearly not admissible – that we denote by $\overline{\omega}_z$. It follows that admissible equilibrium cutoffs points are all the $\omega \in [a, \overline{\omega}_z)$ as $h_z > 0$ only on this interval.

Consider now that $z = n$ and notice that $h_n(\omega) - h_{n+1}(\omega) = \varphi(\omega)\int_{\omega}^{b} p_0(y)dy > 0$ at any ω. It immediately implies that $\overline{\omega}_n > \overline{\omega}_{n+1}$ as h_z is decreasing over $[a, \overline{\omega}_z]$. Now turn to the case where $z = p_0$ and take any $\tilde{p}_0$ such that $\int_a^{\omega} p_0(y)dy \leq \int_a^{\omega} \tilde{p}_0(y)dy$ for all $\omega \in \Omega$. It is easy to see that one can rewrite $h_{p_0}(\omega) = \int_{\omega}^{b}[\varphi(y) - n\varphi(\omega)]p_0(y)dy$. Moreover, we have that $\varphi(y) - n\varphi(\omega)$ is strictly increasing in y. As first-order stochastic dominance directly implies that $h_{p_0}(\omega) \geq h_{\tilde{p}_0}(\omega)$, we must have that $\overline{\omega}_{p_0} \geq \overline{\omega}_{\tilde{p}_0}$.

Finally, assume instead that condition (6) is satisfied. Hence we are back to the case of Theorem 1 which implies that $h_z \leq 0$ for all $\omega \in \Omega$ and thus that $\overline{\omega}_p \leq a$ (once again excluding b). ■

Proof of Proposition 4. Define $\underline{X}(\omega)$ and $\overline{X}(\omega)$ as in the proof of Theorem 1 and let $G(\omega) := \tilde{v}(\underline{X}(\omega), \omega) - \tilde{v}(\overline{X}(\omega), \omega)$. Notice first that G is continuous in ω as $\tilde{v}$ is continuous in each argument and both $\underline{X}(\omega)$ and $\overline{X}(\omega)$ are continuous. There exist a 2-partition informative equilibrium if and only if $G(\omega) = 0$ has a solution in (a, b).

From Proposition 3, we know that only $\omega \in (a, \overline{\omega})$ are admissible cutoff points. By definition, $\overline{\omega}$ corresponds to the state such that $\overline{X}(\overline{\omega}) = n\varphi(\overline{\omega})$ so that

$$G(\overline{\omega}) = \tilde{v}(\underline{X}(\overline{\omega}), \overline{\omega}) - \tilde{v}(n\varphi(\overline{\omega}), \overline{\omega}) < 0,$$

where the inequality directly stems from the fact that $n\varphi(\overline{\omega})$ maximizes $\tilde{v}(\cdot, \overline{\omega})$ (see Lemma 1).

We have that $\underline{X}(a) = \varphi(a)$ and $\overline{X}(a) = \mathbb{E}_{p_0}[\varphi(\tilde{w})]$, which implies that $G(a) = \tilde{v}(\varphi(a), a) - \tilde{v}(\mathbb{E}_{p_0}[\varphi(\tilde{w})], a) > 0$, where the inequality holds by assumption.

Hence, as $G(a) > 0$, $G(\overline{\omega}) < 0$ and G continuous, the intermediate value theorem guarantees that $G(\omega) = 0$ admits at least one solution which implies that a 2-partition informative equilibrium exists. ■

Proof of Theorem 2. In a similar slight abuse of notation as in Lemma 1, let $x = \mathbb{E}_p[\phi(\omega)]$ and $e_i(x) = e_i(p)$. Hence, agent i's expected utility at equilibrium writes $U_i(e_i(x)) = B_i(e_i(x)) - \gamma_i x D(e_i(x), e_{-i}(x))$. The expert's utility writes

$$\tilde{v}(x, \omega) := \sum_{i \in N} [B(e_i(x)) - \gamma_i \phi(\omega) D(e_i(x), e_{-i}(x)] .$$

Differentiating $\tilde{v}$ with respect to x and rearranging gives:

$$\tilde{v}_x(x, \omega) = \sum_{i \in N} \frac{\partial e_i(x)}{\partial x} \left[\frac{\partial B(e_i(x))}{\partial e_i} - \frac{\partial D(e_i(x), e_{-i}(x))}{\partial e_i} \sum_{j \in N} \gamma_j \phi(\omega) \right] .$$

From agent i's first-order condition at equilibrium we have that

$$\frac{\partial B(e_i(x))}{\partial e_i} - \frac{\partial D(e_i(x), e_{-i}(x))}{\partial e_i} \sum_{j \in N} \gamma_j \phi(\omega) = \frac{\partial D(e_i(x), e_{-i}(x))}{\partial e_i} \left[\gamma_i x - \sum_{j \in N} \gamma_j \phi(\omega) \right] ,$$

such that we can immediately rewrite $\tilde{v}$ as follows:

$$\tilde{v}_x(x, \omega) = \sum_{i \in N} \frac{\partial e_i(x)}{\partial x} \frac{\partial D(e_i(x), e_{-i}(x))}{\partial e_i} \left[\gamma_i x - \sum_{j \in N} \gamma_j \phi(\omega) \right]$$

Under the assumption that $\frac{\partial e_i(x)}{\partial x}$ is decreasing in x for all $i \in N$, and from the convexity of D, the sign of $\tilde{v}_x$ depends only on the sign of the terms inside the bracket.

It is immediate that $\tilde{v}_x(x, \omega) > 0$ for all $x \in [\phi(a), \phi(b)]$ and all $\omega \in \Omega$ whenever $\gamma_i \phi(b) - \sum_{j \in N} \gamma_j \phi(a) < 0$ for all $i \in N$. This last condition easily rewrites as equation (7). Applying a similar reasoning to that of Lemma 1, $\tilde{v}_x(x, \omega) > 0$ implies that it is impossible to find $x \neq x'$ such that $\tilde{v}(x, \omega) = \tilde{v}(x', \omega)$ for any x, $x' \in\in [\phi(a), \phi(b)]$ and any $\omega \in \Omega$, or equivalently, that there cannot be an informative communication equilibrium. ■

Proof of Proposition 5: Using Python we compute the explicit values of cutoff type respectively in the one cutoff equilibrium between the Rawlsian, Utilitarian and anti-Rawlsian expert and the agents, and prove that they are ordered as announced. The proof is analytical but very computational. The code generating the computations can be found here: https://www.dropbox.com/scl/fi/7xc02djy606d3dalbvfse/Proof.py?rlkey=hwkju956xvg2t1edvzhunrifl&st=4b7e4j83&dl=0. ■

Proof of Theorem 3. Take the utility function defined by equation (1) and assume $\gamma_i = \gamma$ for all $i \in N$. When each agent i holds belief p and chooses the equilibrium action $e_i(p)$, the expert's expected utility function $\hat{v}(p)$ writes as follows:

$$\begin{aligned}\hat{v}(p) &= n\Big(\frac{1}{1+\gamma n\mathbb{E}_p[\omega]} - \frac{1}{2(1+\gamma n\mathbb{E}_p[\omega])^2}\Big) - n\gamma\frac{\mathbb{E}_p[\omega]}{2}\left(\frac{n}{1+\gamma n\mathbb{E}_p[\omega]}\right)^2 \\ &= \frac{n+2n^2\gamma\mathbb{E}_p[\omega] - n^3\gamma\mathbb{E}_p[\omega]}{2(1+\gamma n\mathbb{E}_p[\omega])^2}.\end{aligned}$$

From the linearity of the expectation operator, proving the concavity of $\hat{v}(p)$ in p is equivalent to prove the concavity in $x \in \Omega$ of

$$\tilde{v}(x) = \frac{n+2n^2\gamma x - n^3\gamma x}{2(1+\gamma n x)^2}.$$

Differentiating twice $\tilde{v}$ with respect to x and simplifying gives:

$$\tilde{v}''(x) = -\frac{n^3\gamma^2\left(1-2n+xn\gamma(n-2)\right)}{(1+n\gamma x)^4},$$

which is negative for all $x \in \Omega$ whenever $1-2n+xn\gamma(n-2) \geq 0$ for all $x \in \Omega$, or equivalently when $\gamma \geq \frac{2n-1}{xn(n-2)}$. Clearly, the right-hand side of this last inequality is decreasing in x. It follows that $\gamma \geq \frac{2n-1}{an(n-2)}$ is a necessary and sufficient condition for the concavity of $\tilde{v}(x)$ in x. ■

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