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Information Manipulation and Climate Agreements

Fuhai Hong and Xiaojian Zhao

It appears that news media and some pro-environmental organizations have the tendency to accentuate or even exaggerate the damage caused by climate change. This article provides a rationale for this tendency by using a modified International Environmental Agreement (IEA) model with asymmetric information. We find that the information manipulation has an instrumental value, as it *ex post* induces more countries to participate in an IEA, which will eventually enhance global welfare. From the *ex ante* perspective, however, the impact that manipulating information has on the level of participation in an IEA and on welfare is ambiguous.

Key words: Asymmetric information, climate change, information transmission, international environmental agreements.

JEL codes: D82, L82, Q54.

Climate change appears to be one of the most pressing problems the world currently faces, and controlling climate change requires substantial abatement of greenhouse gas (GHG) emissions. At the individual level, people are motivated to engage in an emerging lifestyle known as low-carbon living. At the national level, the governments of many countries are subsidizing R&D in wind and solar power and biofuels as replacements for fossil fuels so as to lower GHG emissions. At the international level, countries are negotiating international environmental agreements (IEAs).

The international mass media and pro-environmental campaigns play a crucial role in changing the perceptions of individuals and governments on the climate problem, which enhances their motivation to deliver real impacts on tackling climate change. Notably, Al Gore's documentary *An Inconvenient Truth*, which describes his work in climate change activism, has been credited with raising international public awareness of climate change (e.g., Jacobsen 2011). Moreover, Lofgrena and Nordblom (2010) find that this film indeed affects people's attitudes towards the level of the CO_2 tax.

However, it appears that many of the points made in the film are controversial, and some have argued that it exaggerated the threat of global warming, for example, with regard to rising sea levels.[1] In particular, the film allegedly contains erroneous attempts to link climate change to Hurricane Katrina, as well as the spread of avian influenza and antibiotic-resistant tuberculosis (Ward 2009).

Linking climate change to extreme weather events may be a powerful way to motivate people. However, Ward (2008) reports that in the UK, some environmental groups, as well as scientists and policy makers, push this strategy beyond the limits of the scientific evidence by attributing individual weather events to climate change. Surprisingly, it has even been discovered that the Intergovernmental Panel on Climate Change (IPCC), a well-known intergovernmental scientific body, mistakenly claimed that the Himalayan glaciers would disappear by 2035. The IPCC has tended to over-generalize its research results and accentuate the negative side of climate change. Following its lead, the mainstream media has gone even further.

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[1] See, for example, "Gore's climate film has scientific errors" in The Guardian, October 17, 2007.

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It is a routine and accepted practice that elements in the IPCC reports that indicate the possibility of high levels of crop damage in certain African countries are reported by the media without any qualifying considerations and with such headlines as "IPCC predicts 50% crop reductions in Africa."[2] Hulme (2009) reveals considerable overclaiming in the UK media reports on the IPCC Fourth Assessment; the impacts of climate change were invariably described as "catastrophic, disastrous and fearful," with reporters' own "embellished" interpretations created "through their creative imagination." For example, *The Independent* offered their own description of the impacts of the changes reported by IPCC, ending with the claim that at the high end of the scenario range, "most of life would be exterminated" (Hulme, 2009). Analyzing a sample of print, broadcast and online media coverage over a three-month period between 2005 and 2006, Ereaut and Segnit (2006) concluded that climate change was most commonly constructed through an "alarmist" repertoire as "awesome, terrible" and "immense," characterized by "an inflated or extreme lexicon." Taken together, considerable evidence suggests that international mainstream media and pro-environmental organizations have the tendency to accentuate or even exaggerate the damage caused by climate change.[3]

Our research questions are as follows:

- Why do Al Gore, the IPCC, and the mainstream media varnish their reports to accentuate the damages of climate change?
- Is there any hidden economic rationale for the phenomena?
- What are the welfare consequences to the climate issue?

The literature on IEAs is generally pessimistic regarding the equilibrium level of participation in an IEA, as countries have strong incentives to free ride on others' efforts (see Wagner 2001, or Barrett 2005 for a survey). With insufficient participation, the IEA mechanism seems to have little chance of resolving the problem of climate change. In this article, we suggest that information manipulation, which is generally overlooked in the literature, can be a novel and helpful mechanism for resolving the climate problem. Media bias, or accentuation of the climate damage by pro-environmental organizations, has an instrumental value in that it induces more countries to participate in the IEA.[4]

To parsimoniously capture the functional value of information manipulation on inducing IEA participation, building on a canonical IEA model (e.g. Barrett (1999)), we assume that there are two states of nature. In one state, the climate problem is more severe than in the other. While the countries do not know the realized state, a message sender, which can be interpreted as an international mass medium (or a pro-environmental organization), is better informed about the situation. From the normative point of view, it may be better for the countries to hold a pessimistic view of the climate problem, as it will induce more countries to participate in the IEA in a symmetric mixed strategy participation equilibrium.[5] However, the message sender cannot simply choose the countries' beliefs as it wishes. Nonetheless, the message sender has a channel to influence their beliefs to some extent through information manipulation. In equilibrium, we find that the message sender may have a strict incentive to exaggerate the damages of climate change when it is less severe, which eventually increases the global welfare *ex post*. Interestingly, relying on information

[2] For the source of information of the above discussion, see, for example, "Bias and the IPCC report: Accentuate the negative" in The Economist, July 5, 2010, and "Climate change and the media" in The Economist, February 17, 2010.

[3] There exists an opposite direction of media bias that tends to understate or even deny the extent and impacts of climate change. This sort of media bias may be driven by industry-funded sceptics and the play of public relations (Homles 2009), or the norm of "balanced reporting" in media (e.g. Boykoff and Boykoff 2004). However, this type of media bias is beyond the scope of our analysis.

[4] In this respect, similar to our model, Dessi's (2008) seminal theory of collective memory and cultural transmission explains how information suppression at the societal level alleviates the free-riding problem in general. However, our focus is on the participation decisions of individual countries in an IEA; this feature, which distinguishes the literature on IEAs and coalition formation from standard public good games, is absent in Dessi (2008). Furthermore, our model allows each country to randomize its participation decision to capture the stochastic process in the formation of climate treaties, whereas Dessi (2008) focuses only on pure-strategy investment/effort decisions in a cooperative project. In the meanwhile, to the best of our knowledge, our model is the first IEA model that incorporates asymmetric information in the analysis, which contributes to the understandings of prevalent media bias in the context of climate change.

[5] It is worth noting that our model does not support the view of climate skeptics. In fact, our key result—that overpessimism alleviates the underparticipation problem—implies that the propaganda of climate skepticism may be detrimental to the society.

manipulation will give rise to a negative externality for all the players in the other state when the climate problem is more severe. Intuitively, in this state people will be aware of the message sender's signal suppression, and exhibit rational skepticism even if the problem of climate change is indeed severe. Thus, from the *ex ante* viewpoint, it is not clear whether such information manipulation is welfare enhancing or not.

Our article is related to the literature on media bias and climate change. Groseclose and Milyo (2004) report the prevalence of media bias, while Baron (2006) analyzes its persistence and effects using a theory of news media competition. Seventy-eight percent of the public in the US believe that there is bias in news reporting.[6] One-third of people believe that the media exaggerates the climate change problem (Nisbet and Myers 2007). Zaller (1999) provides an interesting perspective on journalists' practices: "What elite journalists want is a profession that adds something to the news—a profession that not only reports, but also selects, frames, investigates, interprets, and regulates... What journalists add should be, in their ideal, as arresting and manifestly important as possible." In our article, we focus on information bias rather than ideological bias as discussed in Stone (2011). According to Baron (2006), media bias can come from hidden information, which is exactly the instrument with which the message sender manipulates information in our model. Our article suggests a theoretical model that complements existing models of media bias including Baron (2006), Ellman and Germano (2009), and Stone (2011), and provides a new approach to explain the observed exaggeration of climate damages by the mainstream media.

The remainder of this article is organized as follows. The next section presents our IEA model with asymmetric information, and the following section derives the perfect Bayesian equilibrium and discusses its implications. Proofs are relegated to the online supplementary appendix A.1. The aforementioned media bias in climate change issues is endogenous in our model. While we focus on the situation in which the climate problem is sufficiently severe (in both states), for completeness, we provide a detailed analysis for the case when the climate problem is not as severe (at least in one of the states) in the online supplementary appendix A.2. The final section concludes.

Model

Our model builds on the canonical IEA model first proposed by Barrett (1999) in which N identical countries individually decide on whether to participate in an IEA, and then the resulting IEA makes binary decisions on emission abatement.[7] We deviate from this model in two main aspects. First, as in Hong and Karp (2012), we allow countries to randomize their decisions about whether to participate in the IEA. Second, and more importantly, we assume that the damage from climate change is uncertain. Moreover, we introduce a new player in the game: a message sender who has private information about the damage from climate change, and decides whether or not to propagate this information. In the main parts of our analysis, we interpret the message sender as being an international mass medium that has an informational advantage relative to the public.[8] The model details are as follows.

There are $N+2$ risk-neutral players in the game: N *ex ante* identical countries, a message sender, and an IEA. Each country faces a binary decision: whether or not to make one unit of abatement.[9] The cost of one unit of abatement is normalized to 1, where abatement is a global public good. Each country benefits γ from one unit of abatement carried out by any country in the world. Assume that $\gamma < 1 < N\gamma$. The first inequality reflects that it is individually rational for a country acting alone to choose not to abate, whereas the second inequality implies that the world is better off as a result of any country's abatement.

Uncertainty about the damage resulting from climate change is a critical element of the climate problem (Kolstad and Toman 2005). It includes uncertainty in the mapping from GHG emissions to the temperature change and other aspects in climatic change.

[6] See American Association of Newspaper Editors, 1999. Examining our Credibility: Examining Credibility, Explaining Ourselves. Reston, Va. http://www.asne.org.

[7] See also Barrett (2003) and Kolstad (2011).

[8] Alternatively, a pro-environmental organization (e.g., an NGO), if it also has the informational advantage, could actually play the same role of the message sender in our model.

[9] If the cost and benefit of abatement are linear, in equilibrium each country either abates at capacity or does not abate at all. Given linearity, there is no additional loss of generality in assuming that the abatement decision is binary.

Ulph (2004), Kolstad (2007), Kolstad and Ulph (2008), and Karp (2012) study the effect of uncertainty and learning (yet with symmetric information) on equilibrium participation and welfare in an IEA. To capture the role of uncertainty and asymmetric information as simply as possible, we assume that there are two states of nature: state l with probability θ, and state h with probability $1-\theta$, where $0<\theta<1$. In state l, we have $\gamma=\gamma_l$, whereas $\gamma=\gamma_h$ in state h. Let $\gamma_h>\gamma_l$. That is, in state h, the damage from climate change is greater than that in state l, and therefore the benefit of abatement is also greater in state h. While we will restrict our attention to the case in which the climate problem is sufficiently severe (i.e., the benefit of abatement is sufficiently large) by assuming that $\gamma_l \geq 1/2$ in the next section, the online supplementary appendix A.2 analyzes the case for $\gamma_l < 1/2$.

The message sender has private information on the state.[10] Following Dessi (2008), for simplicity we assume that in state l, the message sender receives a signal, L, which is unobservable to the public, whereas in state h, the message sender receives no signal. Upon receiving the signal, the message sender decides whether to transmit it truthfully to countries (people) all over the world. We assume that the message sender cannot "invent" signals; rather, the sender can only decide whether to suppress the signal L in state l.[11] Notably, while the scientific community discovers the true state of nature, the public typically relies on the mass media, who keep abreast of scientific research, to obtain knowledge about the climate problem. Therefore, in general, it is the mass media, not the scientific community, who plays the role of the message sender in our model.

After receiving the signal from the message sender or receiving nothing, each country decides whether to participate in the IEA. If a country decides to participate, then it will follow the IEA's instruction on abatement. A country's participation decision can be made collectively by its citizens, who may or may not know the true state of nature, depending on the message sender's decision.

While each country cares only about its own national welfare, the IEA maximizes the total welfare of its members. In order to minimize the damage resulting from climate change, the message sender tries to maximize the global level of abatement.[12]

In summary, the game consists of the following stages.

- In stage 1, nature determines the state, either h or l. The message sender receives a signal L in state l.
- In stage 2, the message sender decides whether to transmit the signal, L, if the state is l.
- In stage 3, each country decides whether to participate in the IEA.
- In stage 4, the IEA instructs its members whether to engage in abatement, whereas countries outside the agreement (outsiders) make their own decisions individually.
- In stage 5, the state of nature becomes observable to all, and all payoffs are realized.

Palfrey and Rosenthal (1984), Dixit and Olson (2000) and Hong and Karp (2012) all characterize the mixed-strategy participation equilibria of IEA games or games with similar structures with complete information. Following these studies, we assume that countries randomize their participation decisions in stage 3. We focus on the symmetric mixed-strategy equilibrium in which each country joins the IEA with an identical

[10] The assumption that the message sender knows the true state of climate damage is simplified but without loss of generality. Notice that replacing the deterministic γ_i with the expected abatement benefit in state i, $E(\gamma|i)$, for $i=l,h$, does not change our analysis with risk-neutral agents.

[11] As discussed in Dessi (2008), with two states, if information manipulation is interpreted as signal fabrication rather than suppression, we do not need to qualitatively change the game form and the analysis. Specifically, suppose that in state h, the public observes a signal H, while in state l, there is no such signal but the message sender is able to fabricate one and transmit it to the public. This alternative model is technically isomorphic to ours. In both models, the message sender chooses the public's information structure. In our model, the message sender will have signal suppression as shown in the next section, while in the alternative model, it will fabricate a signal that indicates a high level of climate damage. In both models, the message sender engages in information manipulation, which may make the public overpessimistic about the climate issue. Thus, two models equally capture the accentuation of the media on climate damage.

[12] The message sender, as with every country, incurs damage from climate change, which it strives to mitigate. While the assumption that the message sender incurs no abatement cost is implicit in our model, our results do not change qualitatively if we relax it, and allow the message sender to bear an abatement cost. In this case, the objective of the message sender is to maximize global welfare, defined as the abatement benefit net of this cost. Our analysis on the message sender does not apply to those industry-funded media that are motivated to appear skeptical to climate change.

probability of p. Here, we briefly discuss two justifications for our use of mixed strategies. First, while a coordination complexity arises from the use of pure strategies, this is not the case when it comes to symmetric mixed strategies. In many IEA models (for instance, Barrett 1999), there is a pure-strategy equilibrium in which some countries join the IEA and make abatement, whereas others stay out. This sort of pure-strategy equilibrium "requires identical players to choose different strategies in a precisely coordinated manner" (Dixit and Olson 2000).[13] Second, Benedick (2009), a U.S. negotiator for many IEAs, objects to what he considers academics' tendency to view the negotiating process as mechanistic, thereby yielding a deterministic outcome. The failure of the Copenhagen negotiations in 2009 highlights the uncertainty surrounding the ability of nations to agree on a meaningful treaty. While the pure-strategy equilibrium cannot capture this uncertainty, our mixed-strategy equilibrium suffices, as we shall see in the next section.

Analysis

This section focuses on the case when $\gamma_l \geq 1/2$, that is, the climate problem is sufficiently severe, whereas the online supplementary appendix A.2 discusses the case when $\gamma_l < 1/2$. We solve the game backwards.

At stage 4, outsiders do not abate, following their individually rational decisions. We denote the IEA membership by m, and assume that the IEA has the same information set as individual countries on the state. The IEA instructs its members to abate if and only if the expected benefit of one unit of abatement to the coalition is no less than its cost. By $1/2 \leq \gamma_l < \gamma_h < 1$ and the fact that m is an integer, the IEA instructs its members to abate if and only if at least 2 countries have participated in the IEA. With mixed strategies, if the realized membership turns out to be less than 2, the countries fail to arrive at a meaningful treaty.

We then move back to stage 3, the participation game. Let a country's belief about the probability of state l (a belief in state l) be μ, where $0 \leq \mu \leq 1$. Then, the expected benefit of one unit of abatement to a country is

$$\gamma(\mu) \equiv \mu\gamma_l + (1-\mu)\gamma_h. \tag{1}$$

Our assumption on γ_l and γ_h gives rise to $1/2 \leq \gamma(\mu) < 1$. Given the IEA's foregoing decision rule, a country is pivotal when only one other country joins, in which case it obtains an expected gain of $2\gamma(\mu) - 1$ by joining the IEA. However, when at least two other countries join, then the country's additional membership is superfluous from its own point of view: by joining, it suffers an expected loss of $1 - \gamma(\mu)$. In a mixed-strategy equilibrium, a country is indifferent between joining the IEA and staying out, which implies that the net benefit of joining, that is, the expected gain of being pivotal minus the expected loss of being superfluous, should be zero. Through risk neutrality, the equilibrium condition for p as a function of μ is therefore given by

$$\begin{aligned}(N-1)p(1-p)^{N-2}(2\gamma(\mu)-1) \\ = \sum_{i=2}^{N-1} \frac{(N-1!)}{i!(N-1-i)!} p^i (1-p)^{N-1-i} \\ \times (1-\gamma(\mu))\end{aligned} \tag{2}$$

where the left-hand side is the expected gain of being pivotal and the right-hand side is the expected loss of being superfluous. It follows that we obtain the following lemma.

Lemma 1. Each country's participation probability $p(\mu)$ is decreasing in μ.

The online supplementary appendix A.1 contains the proof details of lemmas and propositions contained in this section. Climate damage is less severe in state l, thus belief μ indicates how optimistic a country is regarding climate damage. Lemma 1 implies that the more pessimistic the country is about climate damage, the more likely it is to participate in the IEA in equilibrium. Note that for a more pessimistic country (a lower μ), the expected benefit of abatement $\gamma(\mu)$ is higher; therefore, the gain of participation (when being pivotal), $2\gamma(\mu) - 1$, is larger and the loss of participation (when joining superfluously), $1 - \gamma(\mu)$, is smaller, both of which eventually lead to a higher probability of participation.

Let Ea be the expected level of abatement evaluated at stage 3. We can express Ea as a

[13] Along similar lines, the difficulty of coordination has also motivated the use of mixed strategies in the literature on corporate takeovers (Bagnoli and Lipman 1988; Holmstrom and Nalebuff 1992) and on wars of attrition (Maskin 2003).

function of p as follows:

$$(3)\qquad Ea(p) = \sum_{i=2}^{N} \frac{N!}{i!(N-i)!} p^i (1-p)^{N-i} i$$
$$= Np(1-(1-p)^{N-1})$$

which immediately implies the following lemma.

Lemma 2. The expected level of abatement $Ea(p)$ is increasing in p.

We now consider stage 2. The message sender maximizes the global level of abatement. Thus, its expected payoff is nothing but $\gamma_i Ea(p)$ in state i. Let t be the probability of the message sender transmitting the signal truthfully in state l. We denote a country's belief in state l when receiving signal L by $\mu(L)$ and its belief in state l when receiving nothing by $\mu(\emptyset)$. Obviously, $\mu(L) = 1$ and $\mu(\emptyset) = \frac{\theta(1-t)}{(1-\theta)+\theta(1-t)}$ by Bayes' rule. The following proposition establishes the uniqueness of a perfect Bayesian equilibrium (PBE), which is a pooling equilibrium.

Proposition 1. There is a unique PBE with $t^* = 0$.

In this PBE, the belief system is given by $\mu(\emptyset) = \theta$ and $\mu(L) = 1$, p is determined by (2), and the IEA instructs its members to abate if and only if $m \geq 2$. Proposition 1 implies that no truth-telling separating equilibrium exists in the game. In equilibrium, the message sender never sends the signal indicating a low degree of climate damage. Instead, the sender always suppresses it. Intuitively, given that $\mu(\emptyset) = \theta < \mu(L) = 1$ and that expected abatement is decreasing in μ as implied by Lemmas 1 and 2, the message sender has a strict incentive to suppress the signal L.

While we focus on the case of $\gamma_l \geq 1/2$ in this section, the online supplementary appendix A.2 shows that even if $\gamma_l < 1/2$, the message sender still suppresses the signal as long as the expected benefit of abatement, $\gamma(\theta)$, is sufficiently large. The key insight in this section (and the online appendix A.2) is that the message sender has an incentive to suppress information to achieve a higher expected level of abatement, especially when the climate problem is severe (or equivalently, when the benefit of abatement is large).

These results thus offer an explanation for the phenomenon of information manipulation by the international mass media or other pro-environmental organizations, as discussed in the beginning of the article.

Discussion

In this subsection, we investigate the impacts of signal suppression on IEA membership and welfare. In so doing, we will compare the equilibrium with a benchmark case in which we assume that the message sender commits to truthtelling, that is, the message sender has no instrument of hiding signal L. Therefore, while people's belief in state l when observing L is $\mu^b(L) = 1$, their belief upon observing nothing turns to be $\mu^b(\emptyset) = 0$, where superscript b denotes the benchmark. In this benchmark case, the participation probability is $p(1)$ in state l and $p(0)$ in state h, with $p(1) < p(0)$ by Lemma 1.

To assess the impacts of signal suppression, we first examine state l, where signal suppression is possible. To distinguish the equilibrium from the benchmark case, let superscript s denote the equilibrium (with signal suppression). Proposition 1 shows that in equilibrium, it is optimal for the message sender to suppress the signal in state l. As a result, $\mu^s(\emptyset) = \theta < 1 = \mu^b(L)$, implying that

$$(4)\qquad p(\mu(\emptyset)) = p(\theta) > p(1)$$

where the inequality comes from Lemma 1. Expression (4) means that in state l, the equilibrium participation probability is greater than the participation probability in the benchmark case where the message sender tells the truth. Recall that the probability of participation is higher when countries are more pessimistic about climate damage, as implied by Lemma 1. Thus, by changing beliefs regarding climate damage, the message sender can change the participation probability in the IEA. In state l, compared to the benchmark case of truthtelling, signal suppression renders countries overpessimistic regarding the damage caused by climate change (or, equivalently, overoptimistic about the benefits of abatement), and therefore increases each country's equilibrium participation probability. To slightly alter the notation, let expected membership, Np, be denoted by m. Expression (4) implies that $m_l^s = Np(\theta) > Np(1) = m_l^b$, that is, in state l, the equilibrium expected membership

is greater than the benchmark expected membership.

Given that in equilibrium, a country would have "rational expectation" on the signal suppression (or equivalently, the exaggeration of climate damage), the question arises over why such signal suppression still makes a difference. The reason is that when the message sender indicates high climate damage by sending no signal, a country cannot tell whether the true state of nature is state l in which the message sender has suppressed the signal L, or state h (with high climate damage) in which the message sender cannot send anything. With Bayesian updating, the country would thus believe that the probability of state h is $1-\theta$, even if the true state of nature is actually l.

We further examine the expected payoff for an individual country. Because a country is indifferent between joining the IEA and staying out when playing a mixed strategy, a country's expected payoff at the beginning of stage 3 under state $j\,(\in\{h,l\})$, denoted by $w_j(p)$, is

$$(5)\qquad w_j(p)=\gamma_j\sum_{i=2}^{N-1}\frac{(N-1)!}{i!(N-1-i)!}\times p^i(1-p)^{N-1-i}i$$

which is the country's expected payoff when it stays out. Expression (5) can be rewritten as $w_j(p)=\gamma_j(N-1)p[1-(1-p)^{N-2}]$, which is increasing in p. Hence, by equation (4), we have $w_l^s=w_l(p(\theta))>w_l(p(1))=w_l^b$, meaning that signal suppression by the message sender increases each country's expected payoff in state l, compared to the truthtelling benchmark. This implies that if state l prevails, then it is actually in each country's interest for the message sender to suppress signal L. We thus arrive at the following proposition showing that ignorance of signal L is welfare improving *ex post*.[14]

Proposition 2. Signal suppression, when it happens, increases the expected IEA membership and each country's expected welfare *ex post*, that is, $m_l^s>m_l^b$ *and* $w_l^s>w_l^b$.

[14] The term ex post refers to the situation where the state of nature is realized to be state l (to the message sender), which provides the opportunity for the message sender to suppress the signal.

Besides this result, another message given by the above analysis is that the propaganda of the industry-funded climate skeptics, which renders countries overoptimistic about climate damage, would reduce the level of IEA participation, and thus overall welfare.

However, signal suppression in state l imposes a negative externality on the players in state h. In equilibrium under state h, upon receiving no signal, a country still believes that with probability θ, the state of nature is state l and the message sender has suppressed the signal L. With such Bayesian updating of beliefs, the equilibrium signal suppression in state l leads to over-optimism regarding the damage resulting from climate change in state h. Parallel analysis for the case of state h shows that such over-optimism reduces the equilibrium expected membership and welfare in state h, that is, $m_h^s<m_h^b$ and $w_h^s<w_h^b$, compared with the benchmark case without information manipulation.

The different implications for the two states require us to have an overall assessment on signal suppression from an *ex ante* point of view (i.e., at the time prior to stage 1 when the state of nature is not realized). Let m^k and $w^k(k\in\{s,b\})$ without subscripts denote expected IEA membership and expected welfare of a country, respectively, from the *ex ante* viewpoint. For the benchmark case, prior to stage 1, the expected IEA membership $m^b=\theta m_l^b+(1-\theta)m_h^b=N(\theta p(1)+(1-\theta)p(0))$, and the expected welfare of an individual country is

$$\begin{aligned}(6)\quad w^b&=\theta w_l^b+(1-\theta)w_h^b\\&=\theta w_l(p(1))+(1-\theta)w_h(p(0))\\&=(N-1)\begin{bmatrix}\theta\gamma_l p(1)(1-(1-p(1))^{N-2})\\+(1-\theta)\gamma_h p(0)\\(1-(1-p(0))^{N-2})\end{bmatrix}.\end{aligned}$$

By contrast, in the PBE, each country participates in the IEA with probability $p(\theta)$ in both states. Thus, prior to stage 1, the equilibrium expected membership $m^s=Np(\theta)$, and the equilibrium expected welfare of an individual country is

$$\begin{aligned}(7)\quad w^s&=\theta w_l^s+(1-\theta)w_h^s\\&=\theta w_l(p(\theta))+(1-\theta)w_h(p(\theta))\\&=(N-1)\gamma(\theta)p(\theta)(1-(1-p(\theta))^{N-2})\end{aligned}$$

where $\gamma(\theta)$ is given by equation (1).

To make a comparison, define a function $q(\gamma)$ as implicitly determined by

$$(8) \qquad 1+\frac{\gamma q(N-1)}{(1-\gamma)(1-q)}=\left(\frac{1}{1-q}\right)^{N-1}$$

and another function

$$(9) \qquad W(\gamma)=\gamma q(\gamma)[1-(1-q(\gamma))^{N-2}].$$

Thus, the following proposition shows the conditions under which signal suppression increases membership or welfare from the *ex ante* point of view.

Proposition 3. (*a*) If $q(\gamma)$ is concave (convex) in γ in the interval of $[\gamma_l, \gamma_h]$, then signal suppression increases (decreases) the expected IEA membership from the *ex ante* point of view, that is, $m^s > m^b (m^s < m^b)$.

(*b*) If $W(\gamma)$ is concave (convex) in γ in the interval of $[\gamma_l, \gamma_h]$, then signal suppression increases (decreases) the expected welfare of an individual country, from the *ex ante* perspective, that is, $w^s > w^b (w^s < w^b)$.

Simulations in the following two examples show that $q(\gamma)$ and $W(\gamma)$ are neither globally convex nor globally concave in γ for domain $\gamma \in [1/2, 1)$, implying that signal suppression may have ambiguous effects on both membership and welfare, *ex ante*.

Example 1. Figure 1 shows a numeric example of the effect on expected membership from the *ex ante* perspective. In this example, there are 10 countries involved, that is, $N = 10$.[15] Two states are equally likely a priori ($\theta = 0.5$), where $\gamma_l = 0.55 (> 1/2)$, and γ_h varies from 0.55 to 0.95. The red solid curve shows the equilibrium expected membership, and the blue dotted curve represents the benchmark expected membership. The solid curve is above the dotted curve for moderate values of γ_h, and below it when γ_h is sufficiently large. For example, when $\gamma_h = 0.75$, the equilibrium expected membership is $m^s = 1.3$, which is slightly higher than the benchmark expected membership $m^b = 1.27$. However, when $\gamma_h = 0.95$,

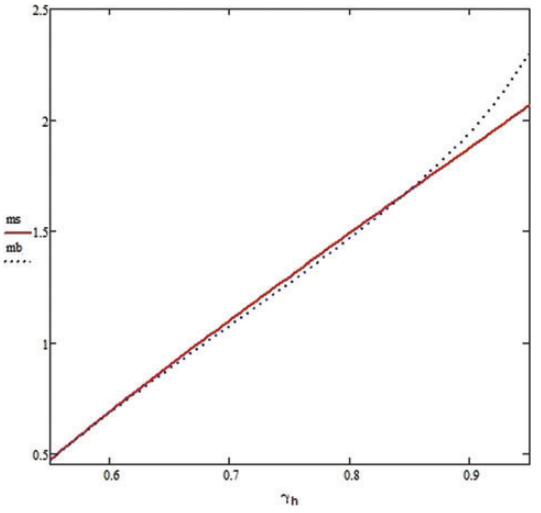

Figure 1. Comparison of equilibrium and benchmark expected membership for $N = 10$, $\gamma_l = 0.55$, and $\theta = 0.5$, with horizontal line γ_h varying from 0.55 to 0.95

the equilibrium expected membership is $m^s = 2.07$, which is lower than the benchmark expected membership $m^b = 2.3$.[16]

Example 2. The ambiguous effect of signal suppression on expected welfare can be exemplified by the case of $N = 3$. Equation (8) degenerates to

$$(10) \qquad 1+\frac{2\gamma}{1-\gamma}\cdot\frac{q}{1-q}=\left(\frac{1}{1-q}\right)^{2}$$

at $N = 3$, the solution to which is $q = 2(2\gamma - 1)/(3\gamma - 1)$. Substituting this into equation (9), evaluated at $N = 3$, yields $W(\gamma) = \gamma[q(\gamma)]^2 = \frac{4\gamma(2\gamma-1)^2}{(3\gamma-1)^2}$. We therefore have $\frac{d^2W(\gamma)}{d\gamma^2} = -\frac{8(3\gamma-2)}{(3\gamma-1)^4}$, which is negative (positive) for $\gamma > (<) 2/3$. Through proposition 3 (*b*), this means that, for $N = 3$, signal suppression increases countries' expected welfare for $\gamma_l > 2/3$, and decreases it for $1/2 \le \gamma_l < \gamma_h < 2/3$, from the *ex ante* perspective.

In example 2, when $1/2 \le \gamma_l < \gamma_h < 2/3$, a perfect commitment of truthtelling can

[15] One distinct feature of the current climate problem is the unequal distribution of carbon emissions: A few main emitters contribute to a predominant majority of global carbon emissions, while many other individual countries' emissions are almost negligible. Therefore, many policy-oriented models on the climate problem assume that the world is composed of a few large countries/regions (e.g. Nordhaus and Boyer 1999).

[16] One should note that the purpose of this example is only to demonstrate the ambiguous implications (in theory) of signal suppression on membership from the ex ante perspective. While the parameters chosen in the example may appear somewhat arbitrary, our key results of the ambiguous effect of signal suppression still hold if we adjust the parameter values.

enhance the *ex ante* welfare. However, in terms of contract theory, such a "commitment of truthtelling" is not renegotiation-proof. Upon receiving a signal L, the message sender has an incentive to renegotiate with itself, and is keen to engage in signal suppression.

To summarize, by information manipulation, the message sender can manage the beliefs of countries regarding the climate problem, and then affect their participation behavior, which is eventually translated to a change of IEA membership and welfare. Proposition 2 shows that when the state of nature has been realized and turned out to be state l (to the message sender), suppression of the signal L increases expected IEA membership and expected welfare. Proposition 3, however, implies that from the *ex ante* point of view before the resolution of the state, we cannot tell whether the equilibrium signal suppression increases or decreases IEA membership and welfare, compared to the benchmark case with commitment to truthtelling.

Conclusions

This article offers a rationale for the phenomenon of climate damage accentuation or exaggeration on the part of the international mainstream media or other pro-environmental organizations. Forming a binding IEA to curb climate change is a matter of urgency (see, e.g., Beccherle and Tirole 2011). The IEA literature generally takes the pessimistic view that an IEA has little chance of success in resolving the climate problem because strong free-riding incentives prevent a sufficient number of countries from participating in that agreement. Using a modified IEA model with two states and asymmetric information, we show that the aforementioned exaggeration of climate damage may alleviate the problem of insufficient IEA participation. When the media or pro-environmental organizations have private information on the damage caused by climate change, in equilibrium they may manipulate this information to increase pessimism regarding climate damage, even though the damage may not be that great. Consequently, more countries (with overpessimistic beliefs about climate damage) will be induced to participate in an IEA in this state, thereby leading to greater global welfare *ex post*. In essence, overpessimism mitigates the problem of underparticipation that is caused by free-riding incentives. However, because people update their beliefs using the Bayesian rule, such information manipulation has a negative externality on the other state when climate damage is really huge, in which case the aforementioned information provider will not be sufficiently trusted even if it indicates the true state. As a result, the participation level falls further in this situation. Overall, information manipulation has an ambiguous effect on IEA membership and global welfare from the *ex ante* perspective.

More generally, our model sheds light on the resolution of various environmental and public problems. In a recent article, Sartzetakis, Xeparadeas, and Petrakis (2012) consider the role of information provision as a policy instrument to supplement environmental taxes. There is also a body of empirical evidence on how the coverage of mass media affects the behavior of consumers and politicians with regard to environmental issues (e.g., Kahn 2007; Jacobsen 2011). This article further explores how the mass media may manipulate the information it privately has to influence behavior related to the environment and the provision of public goods. In addition to other approaches for dealing with the free-riding problem, including taxation, quota systems, privatization, etc., this article introduces a novel mechanism, "information manipulation."

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