Strategic information acquisition and the mitigation of global warming

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Abstract

We consider the strategic role of uncertainty and information acquisition for the mitigation of global warming. Before the countries decide on their contribution to a mitigation of global warming, they may invest in information about the country-specific benefit of reductions of the emissions of greenhouse gases. We show that information acquisition has a substantial strategic value. Countries may prefer not to learn their benefit of climate protection even if information acquisition does not involve a direct cost. This strategic information choice may further decrease the efficiency of the public good provision.

Keywords: Environmental public goods; Private provision of public goods; Global warming; Information acquisition; Uncertainty

JEL classification: H41; D83; Q54
1 Introduction

Global warming and the reduction of emissions of carbon dioxide have been among the most intensively debated issues in international politics in the last decade. Recently, the Stern Review on the Economics of Climate Change has added to the numerous attempts to assess the costs and benefits of climate policy. Both there and in many other discussions of this topic, the relevance of uncertainty for taking action for climate protection is emphasized.\(^1\) But reducing uncertainty does not need to be the only aim of research on the impact of climate change. Countries may use investment in information as an instrument in international climate policy. One kind of uncertainty still relates to the quantitative relationship between the accumulation of greenhouse gases and global temperatures. In addition to this more general question, however, most of the countries involved in climate policy are financing specific research programs to examine the impact of climate change at the national level. In this context, the focus of information acquisition is on country-specific costs and benefits of a global rise in temperatures as well as on the costs relative to other countries. Investments in information seem to be a decisive factor for the achievement of an effective mitigation of global warming. Some countries, however, might prefer not to acquire information.

Contributions to the mitigation of global warming are chosen in the framework of private provision of a global public good: increasing the own investment in the mitigation of greenhouse gases can reduce the effort of other countries. Likewise,

\(^1\)See [19] or [26], chapters 2, 13, 14, 21. Compared to the case of ozone-shield depletion, unresolved uncertainties inhibit the reduction of \(CO_2\) emissions [25].
decisions on information have to be considered not only from an efficiency point of view, but in the context of the contribution game. The possibility of free-riding gives countries an incentive to influence their strategic position at the international level. Persistent uncertainties about costs and benefits of climate change make investments in information a particularly valuable instrument.

In this paper, we focus on the strategic role of information, building on the standard model for private provision of a public good. In order to keep the analysis tractable, we analyze the incentives for information acquisition in a framework with two heterogeneous countries. The countries are uncertain about the economic value they attach to a mitigation of global warming, but they can decide whether or not to invest in information about this country-specific value before they choose their contribution to climate protection. An important characteristic of our model consists in the observability of information acquisition: additional information acquired by a country is publicly observable before the countries decide on their reduction of CO$_2$ emissions. On the one hand, this specification highlights most explicitly the strategic character of investments in information. On the other hand, observability of information acquisition reflects the fact that reports estimating the economic value of global warming at the national level are typically published by the research institutes conducting the studies. Moreover, it is likely that information acquired by a government cannot easily be kept secret, and thus, observability of information is a reasonable assumption. We rule out the possibility of acquiring information about the benefits to other countries. The strategic impact of this type of information
acquisition is similar to the effect in our model.\footnote{One could imagine that some countries try to manipulate information and to produce information in their favor. This type of activity, however, is excluded from our model.}

We will identify two effects of information acquisition. Better information improves the own contribution to a mitigation of global warming. But finding out that the own benefit of a mitigation is large can reduce the contributions of other countries and shift the burden of provision of the public good to the country itself. Hence, information acquisition does not only eliminate uncertainty, it also affects the behavior of other countries. We show that additional information can have a negative value even if the cost of information is zero. Thus, anticipating the impact of the information on other countries’ behavior, countries may have an incentive to remain uninformed. If, in equilibrium, information is not acquired due to strategic considerations, global welfare can be lower than under complete information. We determine conditions under which the strategic information choice negatively affects the efficiency of the resulting mitigation of global warming. This may be a rationale for information provision by a supranational institution. But in addition we demonstrate that there can be too much information acquisition from a welfare point of view even if the information is available without cost. In the latter case, uncertainty helps to overcome the underprovision problem.

The countries’ costs and benefits of emission reductions are assumed to be uncorrelated, with the implication that country-specific information does not inform another country of its cost of global warming. For other environmental public goods such as the protection of the ozone layer, research on ozone-depleting chemicals and the impacts of UV-B radiation provided information about all countries’ damages.
This restricts the possibility of benefiting from being uninformed, and, as we will show, in the extreme case of perfectly correlated values, all countries’ valuations are uncovered in equilibrium.

An important aspect of decision-making under uncertainty is the potential irreversibility of investments which results in an expected value or option value of information revealed in the future [1, 7, 13]. Emissions of CO$_2$ are irreversible in the sense that the stock of greenhouse gases in the atmosphere depreciates very slowly. In the future, however, more information about the damages of climate change will be available. This has implications on the countries’ current contributions to climate protection [9, 10, 11, 15, 27]. Even if countries decide on investments in information, the additional information may only be obtained in the future. We discuss this aspect in an extension of our model, assuming that future contributions can be based on acquired information about the country-specific benefit, but that they are more costly due to the irreversible damages that the delay has caused. Then, a further strategic effect of information acquisition emerges: investments in information can be a credible commitment to delay the own contribution to climate protection until the additional information is available. This, in turn, may affect the other countries’ contributions today.

Our main analysis builds on the standard model of private provision of a public good [2, 8, 23, 25]. Increased risk with regard to the contributions of the other players may make free-riding behavior worse [24]. An important issue for the mitigation of global warming is the implication of uncertainty and learning on international environmental agreements [12, 16]. We add to this literature by studying strategic learn-
ing decisions when contributions to climate protection are chosen non-cooperatively. Our results relate to this work since the non-cooperative equilibrium can influence a bargaining outcome.\footnote{Compare also Hoel [14] who considers the impact of unilateral reductions of emissions on the outcome of international negotiations. Caplan et al. [6] analyze a model where there are winners and losers from global warming. Empirical studies of voluntary contributions to environmental public goods are [18, 20, 21].}

Within the context of voluntary contributions to a public good, the paper is closely related to analyses of strategic behavior prior to public goods games. Konrad [17] considers wealth as the strategic variable, while Robledo [22] analyzes whether players may strategically abstain from purchasing insurance. The underlying effect in these two papers is similar: the players influence their expected marginal utility of income. The strategic role of transfers is considered in [5]. In the context of environmental public goods, investments in technology that lower the contribution cost may be reduced for strategic reasons [4]. Citizens may strategically vote for a government with low preferences for the public good in order to improve the government’s bargaining position [3].

Our work departs from these papers by focusing on the choice of information as a strategic variable. The observability of the information constitutes a strategic disadvantage if high preferences for climate protection are revealed. In this sense, the strategic effect is similar to the strategic voting in [3]. In our context, however, countries cannot influence their benefit of mitigating global warming (or their contribution cost, as in [4]), but they can only decide whether or not to learn this value. Strategic behavior does not necessarily result in an advantage in the contribution game since the outcome of the information acquisition is stochastic. This allows us
to study the trade-off between strategic and efficiency aspects as well as the interaction of the countries’ information choices. In this way, we try to explain strategic considerations in the countries’ behavior with respect to climate research.

2 The formal framework

Consider two countries 1 and 2. Each of them allocates a given wealth $w_i$ between private consumption $x_i$ and a contribution $g_i \geq 0$ to the mitigation of global warming where $g_i$ corresponds to a country’s effort invested in the abatement of $CO_2$ emissions (in monetary terms). Total contributions sum up to $g_1 + g_2 = G$, reflecting the substitutability of the countries’ emissions reductions. The countries’ preferences are described by payoff functions

$$U_i (x_i, G) = x_i + \alpha_i \varphi (G), \quad i = 1, 2$$

that depend on own private consumption and on the benefit of the reduction of $CO_2$ emissions.\(^4\) Contribution costs are normalized to one. The function $\varphi$ is assumed to be strictly increasing and concave ($\varphi' > 0, \varphi'' < 0$), and it translates worldwide efforts into an economic value attached to the resulting mitigation of global warming. The country-specific part of this economic value is expressed by the multiplier $\alpha_i$ which is the key variable of our model and describes the only difference between the countries

\(^4\)Quasilinearity is assumed because it bears out the strategic implications of information acquisition most strongly, and it simplifies the analysis since the optimal mitigation of global warming does not depend on the wealth distribution, but only on the cost-benefit trade-off. Qualitatively, our results do not depend on this specification.
with respect to their preferences.\textsuperscript{5} We will refer to \( \alpha_i \) as country \( i \)’s valuation.

Ex ante, the countries are uncertain about the individual benefit they derive from a mitigation of global warming. Both countries only know the probability distribution of their own valuation and of the other country’s valuation. We assume that \( \alpha_1 \) and \( \alpha_2 \) are asymmetrically distributed in order to account for heterogeneity among the countries with respect to potential damages from global warming. Moreover, the countries’ valuations are assumed to be independent: climate change probably causes high social cost for some (developing) countries while other countries may even benefit from global warming.

Before the countries contribute to a mitigation of global warming, each country has to decide whether to invest in information about its valuation. The information is publicly observable: if \( i \) acquires information, then both countries will update their beliefs about \( i \)’s valuation \( \alpha_i \) in the same way. Hence, there is no private information about a specific country’s cost of global warming. In order to focus on strategic incentive to invest in information, we assume that information acquisition does not involve a direct cost.

Without losing any valuable insight, we concentrate on the case where the valuations \( \alpha_1 \) and \( \alpha_2 \) are independent draws from binary probability distributions with

\[
\begin{align*}
\alpha_i &\in \{l_i,h_i\}, \quad 0 \leq l_i < h_i, \\
\Pr (\alpha_i = h_i) &= p_i, \quad \Pr (\alpha_i = l_i) = 1 - p_i, \quad i = 1, 2.
\end{align*}
\]  

\textsuperscript{5}Thus, the relationship between the accumulation of CO\textsubscript{2} in the atmosphere and global temperatures is - via \( \varphi \) - assumed to be known and common to all countries. The focus is on the country-specific benefit of a mitigation of global warming.
Information acquisition is assumed to yield a perfectly informative signal on the own value.\textsuperscript{6} Note that if country \(i\) decides not to acquire information, both countries will have to choose their contributions based on the common prior about \(\alpha_i\).

The timing of the game is as follows. In stage 1, each country decides whether to acquire information about its valuation. The decisions are made simultaneously. At the beginning of stage 2, the decisions of the two countries and the outcomes of the stage 1 decisions become publicly known, and both countries simultaneously choose their contributions to the global public good. A strategy of a country \(i\) therefore consists of the probability of acquiring information in stage 1, denoted by \(\pi_i \in [0,1]\), and a contribution \(g_i\) in stage 2, conditioned on the information revealed at the beginning of stage 2. To solve the two-stage game, we use the concept of subgame perfect Nash equilibrium.

3 The private provision subgame

We first characterize the private provision equilibrium for given valuations resulting from the decisions in stage 1. Each country \(i\) maximizes

\[
w_i - g_i + A_i \phi (g_i + g_j)
\]

\textsuperscript{6}The restriction to a two-point distribution function facilitates the exposition substantially without influencing the results qualitatively, and it strongly emphasizes the different effects of information acquisition which also emerge for more general probability distributions. With quasilinear preferences, the assumption of a perfectly informative signal is not crucial as countries base their contributions on the (conditional) expected value of \(\alpha_i\).
subject to the budget constraint $x_i + g_i \leq w_i$ and $g_i \geq 0$. Country $i$’s valuation
of the public good - here denoted by $A_i$ - depends on whether or not $i$ acquired
information. If country $i$ acquired information, $A_i$ is equal to its true valuation.
Otherwise, maximization of the expected payoff reduces to an analogous problem
with $A_i$ being the ex ante expected value of $\alpha_i$.

Taking the quasilinear payoff functions into consideration, the solution to this
problem is straightforward. Define the \textit{stand-alone quantity} $\Gamma(A_i)$ of the public good
for a valuation $A_i$ as the solution to the first order condition

$$A_i \varphi'(\Gamma(A_i)) = 1 \quad \text{for } i = 1, 2.$$  \hfill (3)

Note that this is $i$’s desired mitigation level if $g_j = 0$, given its valuation $A_i$ and
provided that its wealth is sufficiently large. It follows from monotonicity and strict
concavity of $\varphi$ that $\Gamma$ is well-defined and strictly increasing in its argument with
$\Gamma(0) = 0$ and $\Gamma(A) = (\varphi')^{-1}(1/A)$ for $A > 0$.

We will generally assume that $w_i$ is never a binding constraint, i.e., we assume
that $w_i \geq \Gamma(h_i)$.\footnote{Wealth constraints change the problem in a way that is interesting and related to the problem we study, and we refer back to this case in the next section.} Then, the equilibrium contributions are well-known to be

$$g_1^* = \Gamma(A_1) \quad \text{and} \quad g_2^* = 0 \quad \text{if } A_1 > A_2,$$

$$g_1^* = 0 \quad \text{and} \quad g_2^* = \Gamma(A_2) \quad \text{if } A_1 < A_2.$$  \hfill (4)

If $A_1 = A_2$, then any vector $(g_1, g_2) \in [0, \Gamma(A_1)]^2$ with $g_1 + g_2 = \Gamma(A_1)$ is an equilib-
rium. (4) characterizes the solution to the private provision game for general values
of $A_1$ and $A_2$: the country with the higher benefit bears the entire burden of $CO_2$ abatement, and the country with the lower benefit free-rides. For the equilibrium, it does not matter whether $A_i$ is an expected value or the true value of country $i$’s mitigation benefit. Thus, (4) describes the equilibrium outcome for the four possible subgames in which none of the countries have acquired information, only country 1 or country 2 has acquired information, or both countries have acquired information.

4 The incentives for information acquisition

Suppose in the following that $E (\alpha_1) < E (\alpha_2)$. Let $m_i := E (\alpha_i), i = 1, 2$. Additionally, we will use the short form notation $\Gamma_{A_i} := \Gamma(A_i)$. As regards the distribution of valuations, the strategic considerations are strongest if

$$\max (l_1, l_2) < m_i < \min (h_1, h_2), \quad i = 1, 2$$  \hspace{1cm} (5)

i.e. the expected value of a country $i$ lies between the two potential valuations of the other country.\(^8\) We will proceed in two steps. First, we determine the best response of a country to a given information decision of the other country. (Recall that $\pi_i = 1$ implies that $i$ uncovers its true valuation with probability 1.) Second, we characterize the set of equilibria of the two-stage game.

\(^8\)If for instance $h_1 < l_2$, information acquisition of one country does not cause an externality on the contribution of the other country: independent of stage 1, only country 2 will contribute in equilibrium.
**Equilibrium analysis.** Consider the best response of a country if the other country decides not to invest in information. We define the *value of information* of a country $i$ as

$$\Delta_i^{\pi_j} := EU_i (\pi_i = 1|\pi_j) - EU_i (\pi_i = 0|\pi_j)$$

where $EU_i (\pi_i|\pi_j)$ is the ex ante expected payoff (prior to the observation of the signal) as function of $\pi_i$ and conditional on $j$’s information decision $\pi_j$.

**Country 1:** Suppose that $\pi_2 = 0$. Due to $E (\alpha_1) < E (\alpha_2)$, it follows from (4) that only country 2 contributes if both countries are uninformed. If country 1 uncovers a high value, equilibrium contributions are $g_1^* = \Gamma (h_1)$ and $g_2^* = 0$. Otherwise, if country 1 is learns a low valuation, $g_1^* = 0$ and $g_2^* = \Gamma (m_2)$. Thus, country 1’s value of information is

$$\Delta_i^{\pi_2=0} = p_1 [h_1 \varphi (\Gamma_{h_1}) - \Gamma_{h_1} - h_1 \varphi (\Gamma_{m_2})]. \quad (6)$$

With probability $1 - p_1$, country 1 uncovers a low value and its payoff is not affected by the information decision as neither the supply of the public good ($\Gamma_{m_2}$) nor country 1’s contribution change. With probability $p_1$, however, the equilibrium contributions change and country 1 bears the burden of $CO_2$ reductions. However, it can adjust the contribution to climate protection to its individually optimal quantity ($\Gamma_{h_1}$). The following properties are straightforward to verify.

**Observation 1** The value of information of country 1 given $\pi_2 = 0$ is
(i) negative if \( h_1 \) is sufficiently close to \( m_2 \) \((\lim_{h_1 \to m_2} \Delta_1^{\pi_2=0} = -\Gamma_1 < 0)\);

(ii) increasing and convex in \( h_1 \).

From Observation 1, it follows that \( \Delta_1^{\pi_2=0} > 0 \) if and only if \( h_1 \) is sufficiently large, i.e. if country 1 potentially has very high cost of global warming.

**Country 2:** Similar to the case of country 1, we can determine country 2’s value of information given that country 1 remained uninformed \((\pi_1 = 0)\). If it uncovers a low value, equilibrium contributions are \( g_1^* = \Gamma(m_1) \) and \( g_2^* = 0 \), and in case of a high value, we have \( g_1^* = 0 \) and \( g_2^* = \Gamma(h_2) \). This yields

\[
\Delta_2^{\pi_1=0} = (1 - p_2) [l_2 \varphi (\Gamma_{m_1}) - (l_2 \varphi (\Gamma_{m_2}) - \Gamma_{m_2})] \\
+ p_2 [(h_2 \varphi (\Gamma_{h_2}) - \Gamma_{h_2}) - (h_2 \varphi (\Gamma_{m_2}) - \Gamma_{m_2})]
\]  

(7)

which, as we show in the appendix, is always positive.

**Lemma 1** Suppose that \( E(\alpha_1) < E(\alpha_2) \) and (5) holds. Then, (i) if country 1 does not acquire information, country 2 always prefers to uncover its valuation, and (ii) if country 2 does not acquire information, country 1 uncovers its valuation if and only if \( h_1 \) is sufficiently large.

The proof of this lemma, as well as those for our other results, is relegated to the appendix. Obviously, country 2 always prefers to learn its mitigation benefit as, without additional information, the other country doesn’t contribute. Uncovering a high valuation, however, allows for an improvement of the own contribution. This adjustment effect increases its payoff. Learning a low valuation would even shift the
full burden of climate protection to the other country. We refer to this effect as a \textit{strategic effect}. Both effects increase the payoff of country 2. Contrarily, if country 1 reveals a high valuation, country 2 reduces its mitigation effort. This negative strategic effect leads to an incentive for country 1 to remain uninformed. Only if $h_1$ is considerably higher than $m_2$, can the improved quantity choice of $G$ outweigh the fact that the provision is now fully paid for by itself. In the latter case, the efficiency aspect of information acquisition dominates the strategic aspect.

It follows directly that, without direct cost of information, there is no equilibrium where both countries do not acquire information. Lemma 1 already determines the equilibrium strategies in a situation where only one country would have the possibility of investing in research on its benefit of a mitigation of global warming. (Alternatively, this situation could arise if one country’s cost of information were prohibitively high.) Furthermore, Lemma 1 applies when one country’s cost of global warming is publicly known.

Now turn to a country’s best response to information acquisition of the other country. Here, it is crucial to distinguish which of the countries may potentially benefit most from a mitigation of global warming, i.e. whether $h_1$ is larger than $h_2$.\footnote{Recall that (5) is still assumed to hold. The distinction of whether $l_1$ is larger than $l_2$ does not change the analysis qualitatively. We will address this issue again later.}

\textit{Case A: $l_i < l_j$, $h_i < h_j$.} Let us first analyze the decision of the country $i \in \{1, 2\}$ whose potential valuations are lower than the other country’s valuations. Hence, if both countries uncover a high value (or both uncover a low value), country $j$ bears
the contribution cost. Given $\pi_j = 1$, country $i$’s value of information is

$$\Delta_{i; h_i < h_j} = (1 - p_i) (1 - p_j) \left[ l_i \phi_1 (\Gamma_i) - (l_i \phi_1 (\Gamma_{m_i}) - \Gamma_{m_i}) \right]$$

$$+ p_i (1 - p_j) \left[ (h_i \phi_{l_i} (\Gamma_{h_i}) - \Gamma_{h_i}) - (h_i \phi_{l_i} (\Gamma_{m_i}) - \Gamma_{m_i}) \right]$$

(8)

which is strictly larger than zero.\textsuperscript{10} With probability $p_j$, the opponent has a high valuation, and, due to $h_i < h_j$, the equilibrium contributions $(g_i^* = 0, g_j^* = \Gamma_{h_j})$ do not depend on $i$’s information decision. With probability $1 - p_j$, $j$’s value is low, and country $i$ pays for the provision if it chooses not to learn its valuation. Therefore, country $i$ prefers to learn its benefit of climate protection, since, with probability $p_i$, it is able to adjust its mitigation effort to $\Gamma_{h_i}$, and with probability $1 - p_i$, it can free-ride on $j$’s contribution.\textsuperscript{11}

\textit{Case B: $l_i > l_j, h_i > h_j$.} Now turn to the country $i \in \{1, 2\}$ with possible valuations $l_i$ and $h_i$ that are higher than $l_j$ and $h_j$, respectively: $i$ contributes if the countries learn either both a high or a low valuation. $i$’s value of information for $\pi_j = 1$ is

$$\Delta_{i; h_i > h_j} = (1 - p_i) (1 - p_j) \left[ (l_i \phi_1 (\Gamma_{l_i}) - \Gamma_{l_i}) - (l_i \phi_1 (\Gamma_{m_i}) - \Gamma_{m_i}) \right]$$

$$+ p_i (1 - p_j) \left[ (h_i \phi_{l_i} (\Gamma_{h_i}) - \Gamma_{h_i}) - (h_i \phi_{l_i} (\Gamma_{m_i}) - \Gamma_{m_i}) \right]$$

$$+ p_i p_j \left[ h_i \phi_{l_i} (\Gamma_{h_i}) - \Gamma_{h_i} - h_i \phi_{l_i} (\Gamma_{h_j}) \right].$$

(9)

The first two terms in (9) are positive: if the other country has a low value (with

\textsuperscript{10}The formal proof parallels the proof of Lemma 1 and is thus omitted.

\textsuperscript{11}This follows from the assumption of $l_i < l_j$. With $l_i > l_j$, country $i$ would also gain in the latter case (both have a low value) due to the adjustment of its contribution from $\Gamma_{m_i}$ to $\Gamma_{l_i}$. 

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probability $1 - p_j$), additional information always improves the individual contribution.\footnote{If $l_i < l_j$, $\Delta\pi^j_{i|h_i > h_j}$ increases by $(1 - p_i)(1 - p_j)[\Gamma_i + l_i\varphi(\Gamma_i) - l_i\varphi(\Gamma_i)] > 0$. The following arguments are still valid.} However, the third term can be negative: if country $j$ has a high benefit of climate protection, $i$ may want to avoid to uncover a high valuation itself. This incentive is strongest if $h_i$ is close to $h_j$, and consequently a contribution of $j$ would be close to $i$'s standalone quantity.

**Observation 2** If $h_i > h_j$ and $\pi_j = 1$, country $i$'s value of information

(i) decreases in $p_j$ and $h_j$ and increases in $h_i$;

(ii) is negative if the difference $h_i - l_i$ is sufficiently small.

If it is more likely that the other country has a high value (i.e. $p_j$ is large), the incentive of uncovering the own value is reduced. Moreover, if the difference between $h_i$ and $l_i$ is sufficiently small, potential gains from an adjustment of the individual mitigation effort are limited, and as $h_i - l_i \to 0$, country $i$'s value of information $\Delta\pi^j_{i|h_i > h_j}$ converges to $-p_i p_j \Gamma m_i < 0$: the negative strategic effect outweighs the increase in the payoff in case the other country learns a low value.

The following proposition describes equilibrium play in stage 1, denoting by country $i$ the country with the higher potential valuation $h_i > h_j$.\footnote{Equilibrium contributions conditional on the history of the game up to stage 2 are characterized in (4). We omit the cases where the value of information is exactly zero and a country is just indifferent between investing and not investing in information.}

**Proposition 1** The equilibrium of the two-stage game is unique. Both countries acquire information if and only if $\Delta\pi^j_{i|h_i > h_j} > 0$. Otherwise, if (a) $\Delta\pi^j_{j|h_i > h_j} = 0$, country...
i remains uninformed and country j acquires information, and if (b) \( \Delta_{j:h_i > h_j} \pi_i = 0 < 0 \), the equilibrium involves mixed strategies.

Proposition 1 shows that, even if information about benefits of climate protection can be obtained without cost, there exists an strategic incentive to remain uninformed that can outweigh potential adjustment gains that come along with more precise information. As the above analysis shows, the equilibrium crucially depends on the underlying probability distributions, i.e. on the potential benefit and on the probabilities of the different outcomes. In particular if the distributions of valuations are similar, the risk of worsening the own strategic position in the mitigation decisions may dominate a potential improvement of the own contribution due to better information. Then, either one country remains uninformed with probability 1, or both countries randomize their information choice. Interestingly, if a country chooses not to learn its benefit of a mitigation of global warming, it is the country that potentially attaches the largest economic value to reductions of CO\(_2\) emissions (the country i with \( h_i > h_j \)). As a result, the country with the highest benefit of climate protection might not contribute to a reduction of CO\(_2\) emissions, but free-ride on the effort of the country with the lower benefit. The following table summarizes the cases where in equilibrium (at least) one country remains uninformed with positive probability.\(^{14}\)

\(^{14}\)In the previous analysis, we assumed throughout that the budget constraints of the countries are never binding. Suppose that both countries uncover a high valuation and \( h_i > h_j \). If \( \Gamma(h_i) > w_i \), equilibrium contributions are \( g_i^* = w_i \), \( g_j^* = \min(w_j, \Gamma(h_j) - w_i) \). The country with the strategic disadvantage in the contribution game is still the country i with \( h_i > h_j \). The impact of information acquisition, however, is weakened since there is no complete free-riding and potential adjustment gains from an increased contribution are restricted. If \( \Gamma(l_i) \geq w_i \), i’s information decision becomes irrelevant.
Table 1: Equilibrium decisions on information.

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<thead>
<tr>
<th>Condition</th>
<th>Decision</th>
<th>Condition</th>
<th>Decision</th>
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<tr>
<td>$h_1 &lt; h_2$ and $\Delta_{\pi_1=1;h_1&lt;h_2} &lt; 0$</td>
<td>$(\pi_1^* = 1, \pi_2^* = 0)$</td>
<td>$h_1 &gt; h_2$ and $\Delta_{\pi_2=1;h_1&gt;h_2} &lt; 0$</td>
<td>mixed strategies</td>
</tr>
<tr>
<td>$\Delta_{\pi_2=0;1,h_1&lt;h_2} &gt; 0$</td>
<td></td>
<td>$\Delta_{\pi_2=0;1,h_1&lt;h_2} &lt; 0$</td>
<td>$(\pi_1^* = 0, \pi_2^* = 1)$</td>
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Welfare considerations. Taking as given that the countries choose their abatement effort non-cooperatively, strategic decisions to remain uninformed may lead to additional inefficiencies: global welfare may be lower than if both countries had chosen to invest in information.\(^{15}\) Due to the quasilinearity of the payoff functions, the analysis can concentrate on the aggregate surplus,

$$S(\alpha_1, \alpha_2, G) = \sum_{i=1,2} \alpha_i \varphi(G) - G. \quad (10)$$

Given the countries’ true valuations, the efficient supply is $G^0(\alpha_1, \alpha_2) = \Gamma(\alpha_1 + \alpha_2)$. Note that, by assumption, costs of information are zero and do not affect welfare.

We distinguish two notions of efficiency: *ex post efficiency*, i.e. welfare depending on the true valuations of the countries, and *ex ante efficiency*, i.e. before the countries learn their valuations and depending on underlying probability distributions. Analyzing ex ante efficiency is particularly relevant for the problem of global warming since it concerns the question of whether a social planner, or supranational institution, that does not know the countries’ true valuations prefers that better information is provided.

\(^{15}\)If a social planner could prescribe the contributions of the countries, she would always prefer to uncover the true valuations.
A priori, it is not clear whether information acquisition is welfare enhancing. To illustrate the impact of information on welfare, let us first consider *ex post efficiency*. As a benchmark, we compare the two cases where either no country acquires information or both countries acquire information.

**Observation 3**  *With information acquisition, ex post aggregate surplus*

(i) *always increases if at least one country uncovers a high value;*

(ii) *decreases if and only if both countries uncover a low value and*

\[
(l_1 + l_2) \phi (\Gamma_{\max\{l_1,l_2\}}) - \Gamma_{\max\{l_1,l_2\}} < (l_1 + l_2) \phi (\Gamma_{m_2}) - \Gamma_{m_2}.
\]  (11)

Observation 3 identifies two potential welfare effects of information acquisition. On the one hand, additional information improves the efficiency of the countries’ contributions. Uncovering a high value is always welfare enhancing since \(G^0(h_i, \alpha_j) \geq \Gamma_{h_i} > \Gamma_{m_2}\), i.e. the equilibrium abatement is closer to the ex post efficient abatement of \(CO_2\) emissions independent of the true valuation of the other country (Observation 3(i)). On the other hand, an uninformed country’s abatement effort could be too high from its individual point of view. This overcontribution effect can improve ex post efficiency if both countries’ true valuations are low (Observation 3(ii)).

Thus, from an *ex ante* point of view, if \(p_1\) and \(p_2\) are sufficiently small, preventing countries from becoming informed can be welfare improving: the chance that the uncertainty about the valuations alleviates the underprovision overcompensates the

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16 A sufficient condition for (11) to be fulfilled is \(l_1 + l_2 > m_2\).
welfare gain which results from uncovering a high benefit of the mitigation of global warming. However, we can formulate (sufficient) conditions such that a strategic decision to remain uninformed always has a negative impact on ex ante efficiency, and therefore, a social planner would like to induce information acquisition.

**Proposition 2** A strategic choice to remain uninformed negatively affects ex ante welfare if one of the following conditions holds:

(C1) $\Gamma(A)$ is convex in $A$;

(C2) $\min \{l_1, l_2\} = 0$.

If the function determining a country’s stand-alone quantity is convex in the valuation, the gain from the adjustment of the individual contributions is strong enough to outweigh a potential welfare gain from an overcontribution at the individual level, regardless of the probability of the two events. Therefore, a choice to remain uninformed decreases the efficiency of the mitigation outcome.\(^{17}\) If (C2) holds, the mitigation outcome is efficient in case both countries uncover a low value: an overcontribution reduces welfare. Thus, under (C1) or (C2), ex ante welfare would be highest if both countries uncovered their benefit of climate protection. The provision of information about the valuations by a third party would be welfare enhancing.

Although (C1) or (C2) may be reasonable assumptions in many cases, there can be situations where both conditions are violated. Consider for example $\varphi(G) =$

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\(^{17}\)Note that convexity of $\Gamma(A_i)$ implies convexity of the supply $G$ (because of $G = \max \{\Gamma(A_1), \Gamma(A_2)\}$), and therefore, the expected value of $G$ over the possible realizations of the valuations is larger than the supply of the public good based on the expected valuations. (C1) is fulfilled e.g. for $\varphi(G) = G^\gamma$, $0 < \gamma < 1$. 

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1 − \exp(-G). We get \( \Gamma(A_i) = -\ln(1/A_i) \) if \( A_i \geq 1 \), and hence, (C1) is not fulfilled. Dependent on the fundamentals of the model, both countries prefer to acquire information, but preventing one country from becoming informed would be welfare enhancing.\(^{18}\) Summing up, we get:

**Claim 1** If both (C1) and (C2) are violated, there can be too much information acquisition in equilibrium.

If \( \Gamma(A_i) \) is strictly concave and, in addition, the probabilities for low values are sufficiently large, the uncertainty leads with high probability to an overcontribution at the individual level. Thus, it might be the case that a social planner would prefer not to provide the information although it is available at no cost. From an ex ante point of view, the uncertainty will then influence in a positive way the countries’ contributions to the mitigation of global warming.

**The effect of correlation.** The strategic advantage of remaining uninformed crucially relies on the assumption of independence of the countries’ cost of global warming. Correlation of the countries’ valuations can be a natural assumption for other environmental public goods such as the depletion of the ozone layer.

Assuming correlated values, an uninformed country \( i \) will update its beliefs about its own benefit in case country \( j \) acquires information. If the correlation is only weak and \( j \) uncovers e.g. a high value, \( i \)'s expectation about its own benefit \( (E(\alpha_i|\alpha_j = h_j)) \) increases, but it may still be lower than \( j \)'s valuation. In this case, the equilibrium

\(^{18}\)Information acquisition of country 1 always leads to a welfare gain compared to no information acquisition because uncovering a low value does not affect the supply \( G \). Hence, preventing both countries from information acquisition can never be optimal.
contributions don’t change, but $i$’s value of information is affected since it becomes more likely that $i$ would uncover a high benefit, too. If instead the valuations are highly correlated, uncovering the own value provides sufficient information about the other country’s valuation.

**Proposition 3** *If the countries’ benefits are perfectly correlated, both countries’ valuations are uncovered in equilibrium.*

Even if there can be an incentive for the country with the lower expected value not to invest in information, the country with the higher expected value prefers to invest in information and uncovers both countries’ valuations. In this sense, inefficiencies resulting from a strategic use of information are not present in other applications such as ozone layer protection.

## 5 Extensions

**Irreversibility and investments in information.** Emissions of $CO_2$ accumulate in the atmosphere and may cause irreversible damages. If additional information is available only in the future, the irreversibility of $CO_2$ emissions affects the optimal timing of the abatement effort. In the following, we illustrate the interaction of decisions on information with the question of timing caused by the irreversibility.

Assume (as before) that in stage 1 of the game, the countries simultaneously decide whether to acquire information about their $\alpha_i$. In stage 2, the countries’ decisions are observed, and the countries choose an abatement effort (*period 1 contributions*). The *information*, however, becomes publicly observable to both countries
only at the beginning of stage 3 in which the countries can again contribute to the public good \((\textit{period 2 contributions})\). If \(g_t^i\) denotes country \(i\)'s contribution in period \(t\), \(i\)'s payoff is

\[
w_i - g_t^1 - qg_t^2 + \alpha_i \varphi (G)
\]

where \(G = \sum_{t=1,2} \sum_{k=1,2} g_k^t\) and \(g_t^i \geq 0\). Moreover, \(g_t^1 + qg_t^2 \leq w_i\). The resulting mitigation of global warming depends on the sum of the efforts in both periods. The marginal cost of contributing in period 2 is denoted by \(q\), and we assume that \(q \geq 1\), i.e. it is more costly to contribute in period 2.\(^{19}\) This reflects the irreversibility effect of delaying the reduction of \(CO_2\) emissions: if it turns out that a country has high cost of global warming, it will be more costly to mitigate the damages than it would have been if the country had invested in climate protection measures already today.

Using the fact that \(\Gamma (A_i/q)\) is the \textit{period 2 standalone quantity} of a country \(i\) with (expected) valuation \(A_i\), given that there were no contributions in period 1, the equilibrium contributions in period 2 are as follows: only the country \(i\) with \(A_i > A_j\) contributes, and it increases potential period 1 contributions up to its desired quantity \(\Gamma (A_i/q)\).\(^{20}\) A country may contribute already in period 1 (based on its expectation) in order to save the higher future contribution cost if a high valuation is uncovered. This effect caused by the irreversibility of emissions has to be weighed against the reduction of the other country’s future contribution.

\(^{19}\)One could imagine that there may be uncertainty not only about \(\alpha_1\) and \(\alpha_2\), but also about \(q\). We take \(q\) as deterministic and identical for both countries in order to keep the analysis as simple as possible.

\(^{20}\)Note that \(\Gamma (A_i/q)\) is decreasing in \(q\): the more costly it is to contribute in the future, the lower are the countries’ period 2 quantities.
If countries can decide on information acquisition, the timing effect of contributing interacts with the strategic incentive to remain uninformed. If \( q \) is sufficiently close to 1 and at least one country invested in information, both countries will always postpone their contributions until the additional information is available since a contribution in period 1 may crowd out potential future contributions of the other country. The countries’ equilibrium decisions on information are the same as in the previous section, and the expected value of information can be negative due to the externality the information has on the other country’s contribution. On the other hand, as \( q \to 1 \), the countries won’t contribute in period 2. In this case, the decisions on information acquisition become irrelevant. For intermediate values of \( q \), however, the balancing of the effects of information can result in asymmetric information decisions and different timing of the contributions.

**Proposition 4** For intermediate values of \( q \), an equilibrium can exist where at least one country remains uninformed with positive probability and the countries contribute in different periods.

As before, an incentive to remain uninformed emerges for the country \( i \) with \( h_i > h_j \). Thus, suppose that \( i \) does not invest in information. If \( j \) invests and \( p_j q < 1 \), it is dominated for \( j \) to contribute in period 1: this saves marginal contribution cost of 1 and causes only expected marginal cost of at most \( p_j q \) in period 2. In turn, if \( i \)’s expected marginal cost of contributing in period 2, \((1 - p_j) q\), is sufficiently high, \( i \) chooses a positive period 1 contribution; \( j \) adds to this contribution if it learns a high benefit. Nevertheless, the negative impact of uncovering a high value can cause an incentive for \( i \) not to invest in information given that \( j \) invests, while \( j \) credibly
postpones any contribution until it has received the additional information. These strategic effects attached to information acquisition in the two-period model may be reflected in arguments in favor of delaying effective climate protection until better information will be available.

**The case of many countries.** The analysis of the two-country case already identified the two effects of information acquisition that persist in the case of more countries: investing in information allows for an adjustment of the individual contribution, but uncovering a high valuation may lead to a reduction of the other countries' contributions. Clearly, the abatement of CO$_2$ emissions involves a larger number of countries whose contributions are important for a mitigation of global warming. The analysis of the previous sections, however, shows that only the countries with the largest (potential) valuations may be contributors whereas countries with a low mitigation benefit free-ride. Moreover, for poor countries whose contributions are subject to budget constraints, information acquisition does not play a role since potential contributions are restricted. Hence, the strategic character of investments in information is only present for countries that may bear the burden of provision, and only a subset of countries is involved in the strategic interaction.

With an increasing number of important contributors, the positive effect of additional information through the improved contribution is still existent, but the strategic effect of information tends to be weakened. This can be illustrated if we replicate our economy $n$ times and obtain two regions $R_1$ and $R_2$, each with $n$ identical countries. Note that this implies that, if a country $i_r$ of region $R_r$ invests in information, all the other countries of this region can infer their cost of climate change. We assume
that identical countries contribute an identical amount to the public good.

As before, if no country of region $R_1$ invests in information, countries of region $R_2$ always prefer to learn their valuation. If no country of region $R_2$ invests and a country $i_1$ of region $R_1$ uncovers a high value, the contribution cost is shared among the countries in this region, and the negative strategic effect of the information is weakened. Similar as in (6), the value of information of country $i_1$ is

$$p_1 \left[ h_1 \varphi \left( \Gamma_{h_1} \right) - \frac{\Gamma_{h_1}}{n} - h_1 \varphi \left( \Gamma_{m_2} \right) \right]$$

which is increasing in $n$ and positive if $n$ is sufficiently large. The same holds for the value of information given that a country of the other region acquires information (where in (8) and (9) all potential contributions $\Gamma(\alpha_i)$ have to replaced by $\Gamma(\alpha_i_r) / n$). Here, not only the negative strategic effect is reduced, but also a positive strategic effect from shifting the burden of contribution to the other country.

6 Conclusion

Uncertainty and information are important determinants for country-specific efforts to reduce the emissions of carbon dioxide. In this paper, we have concentrated on the acquisition of information about the country-specific benefit of a mitigation of global warming. Based on a standard model for private provision of a public good, we showed that the choice of information prior to the interaction has a substantial impact on the equilibrium abatement efforts. We identified conditions under which countries prefer to remain uninformed of their benefit even if they do not have to pay
for the information. A crucial assumption underlying this strategic incentive is the observability of the outcome of the information acquisition. It maps the nature of investments in information in the case of global warming where additional information is obtained via scientific reports estimating the country-specific cost of climate change.

In order to facilitate the exposition, we restricted our analysis to two-point probability distributions of the country-specific benefits. The two effects of information acquisition identified in this case carry over to a general distribution functions: additional information can increase the individual payoff because the own contribution to climate protection can be adjusted; however, it bears a strategic risk since it affects the contributions of the other countries. The latter effect can be negative and, from an ex ante point of view, it can outweigh a potential adjustment gain.

We determined two sufficient conditions under which the resulting strategic information choice has a negative impact on global welfare when, in equilibrium, a country decides not to acquire information. Thus, the provision of information on a supranational level can increase the efficiency of the mitigation outcome. This result may justify the efforts made by supranational institutions with regard to climate research. But if these two conditions are violated, welfare could be higher in case one country remained uninformed: too high contributions from the individual point of view that are caused by uncertainty may alleviate the underprovision problem.

An argument in discussions on climate change is that large investments in the reduction of $CO_2$ emissions should be delayed until better information is available. The optimal timing of these investments, however, is determined by the fact that
emissions of \( CO_2 \) are irreversible. We incorporated the idea of irreversible investments and learning in our model by assuming that the outcome of the information acquisition is only observable in the future, but that future contributions in case of a high benefit of climate protection are more costly due to irreversible damages that \( CO_2 \) emissions might have caused. The strategic interaction of the timing of the contributions and the decisions on information reveals a further strategic effect of information: investments in information may be a rationale for delaying the own contributions and may in turn induce other countries to contribute already today.

A Appendix

A.1 Proof of Lemma 1

Part (ii) follows directly from Observation 1. Part (i) is true since (7) is positive for all \((m_1, p_2, l_2, h_2)\) satisfying (5). This is due to monotonicity of \( \varphi \) and an optimality argument: if \( A_2 \) denotes country 2’s (expected) valuation, by definition of \( \Gamma \),

\[
A_2 \varphi (\Gamma (A_2)) - \Gamma (A_2) > A_2 \varphi (\Gamma (k)) - \Gamma (k) \quad \text{for all } k \neq A_2. \tag{12}
\]

Hence, the second term in (7) is positive. The first term is larger than

\[
[(l_2 \varphi (\Gamma_{m_1}) - \Gamma_{m_1}) - (l_2 \varphi (\Gamma_{m_2}) - \Gamma_{m_2})]
\]

which is positive since \( l_2 < m_1 < m_2 \) and \( l_2 \varphi (G) - G \) is strictly decreasing in \( G \) for all \( G > \Gamma_{l_2} \).
A.2 Proof of Proposition 1

Suppose that $\Delta^2_{j;h_i > h_j} > 0$. Since $\Delta^1_{j;h_i > h_j} > 0$, there is an equilibrium where both countries acquire information. With Lemma 1, information acquisition is a strictly dominant strategy for country 2. Thus, the equilibrium is unique.

Now suppose instead that $\Delta^1_{j;h_i > h_j} < 0$. There exists an equilibrium where $i$ remains uninformed and $j$ acquires information iff $\Delta^1_{j;h_i > h_j} = 0$ is positive. (If $j = 2$, $\Delta^0_{j;h_i > h_j} > 0$ is always fulfilled.) Due to $\Delta^1_{j;h_i > h_j} > 0$, acquiring information is strictly dominant for country $j$ which shows uniqueness.

In the remaining case of $\Delta^2_{j;h_i > h_j} < 0$ and $\Delta^0_{j;h_i > h_j} < 0$, the latter condition implies $j = 1$. There is no equilibrium in pure strategies: country 1 always prefers to choose the same action as country 2, whereas country 2 uncovers its value if and only if 1 does not learn. Hence, consider equilibria in mixed strategies. Country $i$ randomizes if and only if $(1 - \pi_i^*) \Delta^0_{j;h_i > h_j} + \pi_i^* \Delta^1_{j;h_i > h_j} = 0$. Thus, in the unique equilibrium,

$$\pi_1^* = \frac{\Delta^2_{j;h_i > h_j}}{\Delta^2_{j;h_i > h_j} - \Delta^1_{j;h_i > h_j} < 0} \in (0, 1), \quad \pi_2^* = \frac{-\Delta^2_{j;h_i > h_j}}{\Delta^2_{j;h_i > h_j} - \Delta^1_{j;h_i > h_j} < 0} \in (0, 1).$$

A.3 Proof of Proposition 2

Whenever $\Delta^1_{i;h_i > h_j} < 0$, either $i$ remains uninformed or the equilibrium is in mixed strategies. Consider the pure strategy equilibrium and examine

$$E \left[ S(\alpha_i, \alpha_j, G) \mid \pi_i = 1, \pi_j = 1 \right] - E \left[ S(\alpha_i, \alpha_j, G) \mid \pi_i = 0, \pi_j = 1 \right]$$
which is equal to

\[
(1 - p_j) \left[ (1 - p_i) S(l_i, l_j, \Gamma_{\max\{i, l_j\}}) + p_i S(h_i, l_j, \Gamma_{h_i}) - S(m_i, l_j, \Gamma_{m_i}) \right] \\
+ p_i p_j \left[ S(h_i, h_j, \Gamma_{\max\{h_i, h_j\}}) - S(h_i, h_j, \Gamma_{h_j}) \right]
\] (13)

The second term in (13) is non-negative. (It is positive in the pure strategy equilibrium due to \( h_i > h_j \).) The first term is positive for all \( p_i \) iff \( S(A_i, l_j, \Gamma_{\max\{A_i, l_j\}}) \) is convex in \( A_i \). For \( A_i > l_j \), we have

\[
\frac{\partial S(A_i, l_j, \Gamma_{\max\{A_i, l_j\}})}{\partial A_i} = \varphi' (\Gamma (A_i)) + \frac{l_i}{A_i} \Gamma' (A_i)
\]

\[
\frac{\partial^2 S(A_i, l_j, \Gamma_{\max\{A_i, l_j\}})}{\partial A_i^2} = \frac{\Gamma''(A_i)}{A_i} \left( 1 - \frac{l_i}{A_i} \right) + \frac{l_i}{A_i} \Gamma''' (A_i).
\]

For \( A_i < l_j \), \( \partial S(A_i, l_j, \Gamma_{\max\{A_i, l_j\}}) / \partial A_i \) is constant and smaller than the slope of \( S \) for \( A_i > l_j \). Thus, \((C1)\) is a sufficient condition for convexity of \( S(A_i, l_j, \Gamma_{\max\{A_i, l_j\}}) \) and hence for \( \Delta E[S] \) being strictly positive if in equilibrium only \( i \) remained uninformed.

In the mixed strategy equilibrium, the number of informed countries depends on the outcome of the randomization. Welfare without information acquisition is lower than if only country 1 uncovered its value: learning a low value has no effect on total contributions, but uncovering a high value is welfare enhancing. Moreover, as above, if exactly one country remained uninformed, welfare is lower than under complete information if \((C1)\) holds. Thus ex ante welfare is lower in the mixed strategy equilibrium than under complete information.

\((C2)\) follows directly from Observation 3(i) and the fact that (11) is violated if \( \min \{l_1, l_2\} = 0 \).
A.4 Proof of Claim 1

Consider as example $\varphi(G) = 1 - \exp(-G)$. Solving the first order condition yields

$$
\Gamma(A_i) = \begin{cases} 
0 & \text{if } A_i < 1 \\
-\ln\left(\frac{1}{A_i}\right) & \text{if } A_i \geq 1
\end{cases},
$$

and thus (C1) is violated since $\Gamma''(A_i) = -1/A_i^2 < 0$. If for instance

$$
l_1 = 3, \ l_2 = 2.8, \ h_1 = 8, \ h_2 = 10, \ p_1 = p_2 = 0.2,
$$

we get $\Delta_{2;h_2>h_1}^{x_1=1} \approx 0.75$, and both countries acquire information in stage 1. Computation of the expected surplus dependent on $\pi_1$ and $\pi_2$ yields

$$
E[S|\pi_1 = \pi_2 = 1] \approx 5.01, \ E[S|\pi_1 = 1, \pi_2 = 0] \approx 5.00,
$$

$$
E[S|\pi_1 = 0, \pi_2 = 1] \approx 5.03, \ E[S|\pi_1 = \pi_2 = 0] \approx 4.85.
$$

A social planner would choose $\pi_1 = 0$ and $\pi_2 = 1$.

A.5 Proof of Proposition 3

If a country $j$ invests in information, it uncovers both countries’ valuations and $i$’s information decision becomes irrelevant. Suppose that $l_1 < l_2$ and $h_1 < h_2$. In this case, country 2’s value of information is smallest since with information, it always
contributes. Because of

\[
\Delta_2^{\pi_1=0} = (1 - p_2) [(l_2 \varphi(\Gamma_{l_2}) - \Gamma_{l_2}) - (l_2 \varphi(\Gamma_{m_2}) - \Gamma_{m_2})]
+ p_2 [(h_2 \varphi(\Gamma_{h_2}) - \Gamma_{h_2}) - (h_2 \varphi(\Gamma_{m_2}) - \Gamma_{m_2})] > 0,
\]

country 2 always invests in information if country 1 does not invest. If \(\Delta_1^{\pi_2=0} < 0\) (which may be the case if \(l_1 > l_2\) and \(h_1 > h_2\)), country 2 acquires the information; otherwise either of the countries may invest.

### A.6 Proof of Proposition 4

Suppose that \(h_i > h_j\). We show that \(\Delta_{i_{h_i > h_j}}^{\pi_{i-1}}\) can be negative. Then, in equilibrium, either \(i\) remains uninformed with probability 1, or both countries randomize their information choice. Note first that, if \(A_i\) denotes a country \(i\)'s (expected) valuation in period 2 (dependent on whether or not \(i\) acquired information), period 2 contributions for \(A_i > A_j\) are \(g_i^2 = \max(\Gamma (A_i/q) - g_i^1 - g_j^1, 0)\) and \(g_j^2 = 0\).

For simplicity, let us assume that \(l_1 = l_2 = 0\). The most interesting case is

\[
q < \frac{1}{p_1} \text{ and } q < \frac{1}{p_2}, \tag{14}
\]

(14) implies that, if country \(j\) invested in information, it has a dominant strategy not to contribute in period 1: if \(i\) remained uninformed,

\[
\frac{\partial U_j (g_j^1)}{\partial g_j} = \begin{cases} 
-1 + p_j q & \text{if } 0 < g_j^1 \leq \max \{\Gamma_{h_j/q} - g_i^1, 0\} \\
-1 + p_j h_j \varphi' (g_i^1 + g_j^1) & \text{if } g_j^1 > \max \{\Gamma_{h_j/q} - g_i^1, 0\}
\end{cases}
\]
which, with (14), is negative for all \(g_j^1 > 0\). (For \(g_j^1 > \Gamma (h_j/q) - g_i^1\), this follows from \(\partial U_j (g_j^1)/\partial g_j^1 < -1 + p_j h_j (q/h_j) < 0\).) If \(i\) acquired information, an equivalent argument shows that contributing in period 1 is dominated both countries.

Now suppose that \(\pi_j = 1\). If \(i\) acquires information, \(i\) only contributes in period 2 if it has a high value, and its expected payoff is

\[-p_i q \Gamma (h_i/q) + p_i h_i \varphi (\Gamma (h_i/q)).\]

If \(i\) remained uninformed, we have \(g_j^1 = 0\) and thus

\[
\frac{\partial U_i (g_i^1)}{\partial g_i^1} = \begin{cases} 
-1 + (1 - p_j) q & \text{if } 0 < g_i^1 \leq \Gamma (m_i/q) \\
-1 + (1 - p_j) m_i \varphi' (g_i^1) & \text{if } \Gamma (m_i/q) < g_i^1 < \Gamma (h_j/q) \\
-1 + m_i \varphi' (g_i^1) & \text{if } g_i^1 > \Gamma (h_j/q) 
\end{cases}
\]

Here, \(i\)'s optimal period 1 contribution (and its expected payoff) depends on the parameter values. If \(q > 1/(1 - p_j)\), \(i\) contributes in period 1, and its optimal contribution is either \(\Gamma ((1 - p_j) m_i)\) or \(\Gamma (m_i)\). If instead \(q < 1/(1 - p_j)\), equilibrium candidates are \(g_i^1 = 0\) and \(g_i^1 = \Gamma (m_i)\). In both cases, (14) implies that \(\Gamma (h_j/q) > g_i^1\), and thus \(j\) contributes a positive amount in period 2 if \(\alpha_j = h_j\).

If \(q > 1/(1 - p_j)\), \(i\)'s value of information \(\Delta_{i:h_i > h_j}^{\pi_j=1}\) is weakly smaller than

\[-p_i q \Gamma_{h_i/q} + p_i h_i \varphi (\Gamma_{h_i/q}) - [-\Gamma_{(1-p_j)m_i} + (1 - p_j) m_i \varphi (\Gamma_{(1-p_j)m_i}) + p_j m_i \varphi (\Gamma_{h_j/q})]\]
which is equal to

\[- [(1 - p_j) m_i \varphi \left( \Gamma_{(1-p_j)m_i} \right) - \Gamma_{(1-p_j)m_i}] + [(1 - p_j) m_i \varphi \left( \Gamma_{hi/q} \right) - \Gamma_{hi/q}] \]

\[+ (1 - p_i q) \Gamma_{hi/q} + p_j m_i \left( \varphi \left( \Gamma_{hi/q} \right) - \varphi \left( \Gamma_{hj/q} \right) \right) \] .

(15)

As the first line in (15) is negative (by the same argument as in (12)), \( \Delta_{i;hi>h_j}^{\pi_j=1} \) is negative if \( h_j \) is sufficiently close to \( h_i \) and \( q \) is sufficiently close to \( 1/p_i \), i.e. if the negative effect from uncovering a high value is strong. If \( q < 1/(1 - p_j) \), similar transformations show that, again if \( h_j \) is sufficiently close to \( h_i \) and \( q \) is sufficiently close to \( 1/p_i \), \( \Delta_{i;hi>h_j}^{\pi_j=1} < 0 \).

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