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ABSTRACT

Strategic Information Acquisition and the Mitigation of Global Warming

by Florian Morath *

We consider the strategic role of uncertainty and information acquisition for the mitigation of global warming which is modeled using a standard framework for private provision of a public good. Prior to the voluntary contribution mechanism, we allow for investments 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 in the following interaction. Countries may prefer not to learn their valuation of the public good 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: Private provision of public goods, environmental public goods, information acquisition, uncertainty, global warming

JEL Classification: H41, D83, Q54

ZUSAMMENFASSUNG

Strategische Informationsakquise und der Kampf gegen den Klimawandel

Diese Arbeit untersucht die strategische Bedeutung von Unsicherheit und Informationsakquise für den Kampf gegen den Klimawandel, der im Standardrahmen der privaten Bereitstellung eines öffentlichen Gutes abgebildet wird. Bevor die Beiträge zum öffentlichen Gut auf freiwilliger Basis gewählt werden, haben Länder die Möglichkeit, in Information über den länderspezifischen Nutzen einer Reduzierung der CO2-Emissionen zu investieren. Es wird gezeigt, dass der Informationsakquise ein substantieller strategischer Wert in der nachgelagerten Interaktion zukommt. Selbst wenn durch die Informationsakquise keine direkten Kosten anfallen, können Länder es vorziehen, ihre Bewertung des öffentlichen Gutes nicht zu erfahren. Diese strategische Informationsentscheidung kann die Effizienz der Bereitstellung des öffentlichen Gutes zusätzlich beeinträchtigen.

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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 is not the only aim of research on the impact of climate change. Investment in information can also be used as an instrument in international climate policy. Assuming that a large part of the research is publicly funded, the huge number of publications on climate change may serve as indicative of the importance of information. One kind of uncertainty still relates to the quantitative relationship between the accumulation of greenhouse gases and global temperatures. However, in addition to this more general question, 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 the country-specific costs and benefits of a global rise in temperatures as well as on the costs relative to other countries. Some countries, however, might prefer not to acquire information about this cost.

The mitigation of global warming is one of the most important examples for the private provision of a (pure) public good.[2] The possibility of free-riding gives countries an incentive to influence their strategic position in the interaction. Manipulation of individual characteristics may serve as a commitment device: it may establish the possibility of a credible commitment to free ride. But in return, such manipulations are likely to lower the efficiency of the outcome of the interaction.

In this paper, we focus on the strategic role of information acquisition. Finding out that the individual benefit of the mitigation of global warming is large could reduce the contributions of other countries and shift the burden

[1] Cf. Stern (2006), chapters 2, 13, 14, 21. Furthermore, see e.g. McKibbin and Wilcoxen (2002) or Sandler (2004) who points out that, compared to the case of ozone-shield depletion, unresolved uncertainties inhibit the reduction of CO_2 emissions.

[2] See e.g. Hoel (1991) and Sandler (1992, 2004) for an analysis of global climate as a public good, Caplan et al. (1999) for a model where countries are affected differently by global warming, and for empirical studies Murdoch and Sandler (1997), Murdoch et al. (1997), and Fredriksson and Gaston (2000).

of provision of the public good to the country itself. Hence, investments in information do not only eliminate uncertainty and improve the efficiency of the own contribution. Additional information will also affect the behavior of other countries.

In order to elaborate on the incentives for information acquisition, we stay as close as possible to the standard model for the private provision of a public good. However, we extend this framework by including an information decision. We assume that, ex ante, countries are uncertain about the economic value they attach to a reduction of CO_2 emissions. Before the contributions to the public good are chosen, countries can decide whether or not to invest in information about this country-specific value. An important characteristic of our model consists in the observability of the information acquisition: additional information acquired by a country is publicly observable before the countries enter into the private provision game. 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 a national level are typically published by the research institutes conducting the studies. For the case of international public goods, it is likely that information acquired by a government cannot easily be kept secret, and thus, observability of information is a reasonable assumption. In this paper, we rule out the possibility of acquiring information about the benefits to other countries. The strategic effect of this type of information acquisition is similar to the effect that occurs in our model.[3]

We will identify two effects of information acquisition. Additional information allows for an adjustment of the individual contribution. Although this effect increases the individual payoff, countries have to take into account the reaction of the other countries in the private provision game: knowing about a high valuation of a country, they may reduce their own contribution. We analyze this trade-off and show that additional information may have a negative value even if the cost of this 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, welfare may be lower

[3]One could imagine that some countries try to manipulate information and produce information in their favor. This type of activity, however, is excluded from our model because we are aiming at the strategic value of being uninformed.

than under complete information. We will determine conditions under which the strategic information choice negatively affects the efficiency of the public good provision. 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.

Our analysis builds on the standard model of private provision of a public good that has been intensively studied in the literature. Among the main contributions are McGuire (1974), Warr (1982, 1983), Cornes and Sandler (1984, 1985), Bergstrom et al. (1986), and Andreoni (1988). Andreoni and McGuire (1993) describe the set of contributors based on the individually optimal supply of the public good. Sandler et al. (1987) indicate the role of uncertainty by showing that increased risk with regard to the contributions of the other players may make free-riding behavior worse.

Within the context of voluntary contributions to a public good, the paper is more closely related to analyses of strategic behavior prior to public goods games. By making observed choices prior to the actual contribution game, players may change their co-players' contribution behavior in a way that is advantageous for them. In particular, five different strategic choices have been analyzed:

Konrad (1994) considers wealth or income in the actual contribution stage as the strategic variable. He shows that individuals have an incentive to reduce their disposable income. The resulting reduction of the own contribution increases the marginal utility of the public good which leads to larger contributions of the other individuals.

Robledo (1999) analyzes whether players may strategically abstain from purchasing insurance. The underlying effect in his framework is related to Konrad (1994): the insurance decision changes the expected marginal utility of income. He shows that, under the assumption of prudence, a player may prefer higher uncertainty because of the effect on both players' marginal utility that follows a desired stabilization of private consumption. It is interesting to see that very different instruments (early expenditure on the one hand, and insurance purchases on the other hand) can have rather similar strategic effects.

Furthermore, several papers consider the strategic role of contribution cost. Buchholz et al. (1998) show that low productivity agents have a strategic advantage in the contribution game. A similar effect arises in Konrad and Lommerud (1995) who study non-cooperative provision of family public goods. In the context of environmental public goods, Buchholz and Konrad (1994) show that investments in technology that lower the contribution cost may be reduced for strategic reasons. Having high contribution cost corresponds to a low public good valuation in our model. However, we do not allow countries to manipulate this valuation. The strategic behavior that we may observe consists in the choice of information about the cost of global warming.

Buchholz et al. (2005) analyze the role of the institutional structure for the provision of international public goods. In their model, citizens may strategically vote for a government with low preferences for the public good in order to improve the government's bargaining position.

The strategic role of transfers is considered by Vicary (1990), Buchholz and Konrad (1995), and Ihori (1996). The latter two papers focus on unconditional transfers in a framework with productivity differentials. The incentive for such transfers emerges if individuals have different costs of making contributions. Vicary (1990) studies voluntary income transfers from rich to poor individuals in a weakest-link model where the supply of the public good is determined by the lowest contribution.

Our work departs from these papers by focusing on the choice of information as a strategic variable. There may be an incentive to disregard information that is available at zero cost. The observability of the information constitutes a strategic disadvantage if high preferences for the public good are revealed. In this sense, the strategic effect is similar to the strategic voting in Buchholz et al. (2005). However, in our model, countries cannot choose their valuation in the upcoming private provision game, but they can only decide on the information about this country-specific value. Hence, in contrast to the papers above, the 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 the possibility of optimizing the individual contribution on the one hand, and the effect on the other country's behavior on the other hand. Moreover, we are able to analyze the strategic interactions of the countries' information choices since the optimal decisions will depend on the other country's choice and on the relative benefit compared to the other country. By including information acquisition, we try to explain strategic considerations in the countries' behavior with respect to climate research.

We proceed as follows: the next section describes the model, and section 3 characterizes the equilibrium of the private provision game. Drawing on the continuation payoffs in the public goods game, section 4 analyzes the incentives for information acquisition and implications for welfare. Finally, Section 5 concludes.

2 The formal framework

Consider two countries 1 and 2.[4] Each of them allocates a given wealth w_i between private consumption x_i and a contribution $g_i \geq 0$ to a public good. Total contributions sum up to $g_1 + g_2 = G$. The use of this aggregation technology reflects the substitutability of countries' reductions of CO_2 emissions. The countries' preferences are described by payoff functions

$$U_i(x_i, G) = x_i + \alpha_i \varphi(G), \qquad i = 1, 2 \tag{1}$$

where the payoff depends on own private consumption and the total quantity of the public good. Contribution costs are normalized to one. The function φ is assumed to be strictly increasing and concave, $\varphi' > 0$, $\varphi'' < 0$. A key variable is α_i, the weight that a country i gives to the benefit from the public good. This weight is idiosyncractic and describes the only difference between the countries with respect to their preferences. For this reason we say that α_i is country i's *valuation* or type. Referring back to the case of climate change, country i's contribution g_i can be interpreted as the effort invested in the abatement of CO_2 emissions (in monetary terms) whereas φ is the technology that translates worldwide efforts into an economic value attached to the resulting mitigation of global warming. The country-specific part of this economic value is then expressed by the multiplier α_i.[5]

Quasilinearity is assumed because it bears out the strategic implications of information acquisition most strongly. As in partial equilibrium analysis, quasilinear preferences map the absence of income effects and are a natural assumption in the case of global warming relying on the fact that countries spend only a small portion of their total expenditures on climate protection. Qualitatively, our results do not depend on this specification.

[4] The two-country case already identifies the effects of information acquisition which are also present in the case of N countries. With more than two countries, however, the number of different cases which have to be taken into account in section 4 increases exponentially.

[5] Thus, the relationship between the accumulation of CO_2 in the atmosphere and global temperatures is - via φ - assumed to be known and common to all countries. The focus is on the country-specific benefit of a mitigation of global warming.

Ex ante, the countries are uncertain about the individual benefit they derive from the supply of the public good. Both countries know the probability distribution of their own valuation and of the other country's valuation. The prior distribution of country i's type is denoted by $F_i(\alpha_i)$ with type space $[0, \alpha_{\max})$.[6] The countries' types 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.

Prior to the contribution game, each country has to decide whether to receive a signal about its valuation before entering into the private provision game. This information acquisition does not involve a direct cost, and the information is publicly observable: if i acquires information, then both countries will update their beliefs about i's valuation α_i in the same way. Hence, there is no private information about a specific country's cost of global warming.

Without losing any valuable insight, we concentrate on the case where the types α_1 and α_2 are drawn independently from binary probability distributions F_1 and F_2. Furthermore, information acquisition is assumed to yield a perfectly informative signal on the own type.[7] This specification facilitates the exposition substantially without influencing the results qualitatively, and it strongly emphasizes the different effects of information acquisition which also emerge for a more general distribution of types. Accordingly, let

$$\begin{array}{l} \alpha_i \in \{l_i, h_i\}, \quad l_i < h_i, \\ \Pr(\alpha_i = h_i) = p_i, \ \Pr(\alpha_i = l_i) = 1 - p_i, \quad i = 1, 2 . \end{array} \tag{2}$$

Note that if country i decides not to acquire information, both countries will have to choose their contributions based on the common prior about α_i.

[6] Our analysis will concentrate on two-point distributions of types. The upper bound of the support is used to avoid corner solutions where wealth constraints are binding, i.e. the entire expenditures of a country are on climate protection. $\alpha_i \geq 0$ corresponds to the assumption of $g_i \geq 0$ as it is standard in models of public goods provision.

[7] Considering the cost of global warming, the assumption of a perfectly informative signal seems to be extreme. In the case of quasilinear preferences, this reduced form can be deduced from a more general information structure assuming a binary signal $s_i \in S_i$ where country i's signal space $S_i = \{L_i, H_i\}$. Let $F_i : [0, \alpha_{\max}) \times S_i \to [0, 1]$ be the joint probability distribution of the valuation α_i and the signal s_i. (Assuming that the cost of information acquisition is zero, we are not required to restrict this distribution on the effort invested in information and the information precision, respectively.) Given a signal s_i, countries update their beliefs, and they base their contributions on the conditional expected value of their type which can thus be defined as $l_i := E(\alpha_i | s_i = L_i)$ and $h_i := E(\alpha_i | s_i = H_i)$.

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 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 for the equilibria of the 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. As in the standard approach (Bergstrom et al., 1986), each country i maximizes

$$w_i - g_i + A_i \varphi \left(g_i + G_{-i} \right)$$

subject to the budget constraint $x_i + g_i \leq w_i$ and $g_i \geq 0$. (G_{-i} are the aggregate contributions of the countries other than i.) Here, $A_i \in [0, \alpha_{\max})$ is i's *valuation* of the public good. This valuation 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 α_i.[8]

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

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

Note that this is the quantity of the public good that i would be willing to contribute on its own if $G_{-i} = 0$, given its valuation A_i and provided that its wealth is sufficiently large. It follows from monotonicity and strict concavity of φ that Γ is well-defined and strictly increasing in its argument with $\Gamma(0) = 0$ and $\Gamma(A) = (\varphi')^{-1} \left(\frac{1}{A} \right)$ for $A > 0$.

[8] This is due to the multiplicative payoff structure. Hence, the analysis for a general distribution of types is similar to our approach.

We will generally assume that w_i is never a binding constraint, i.e., we assume that $w_i \geq \Gamma(\alpha_{\max})$.[9] Then, the equilibrium contributions are well-known to be

$$\begin{array}{llll} g_1^* = \Gamma(A_1) & \text{and} \;\; g_2^* = 0 & \text{if} & A_1 > A_2 \;, \\ g_1^* = 0 & \text{and} \;\; g_2^* = \Gamma(A_2) & \text{if} & A_1 < A_2 \;. \end{array} \tag{4}$$

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 equilibrium. (4) characterizes the solution to the private provision game for general values of A_1 and A_2. For the equilibrium, it does not matter whether A_i is an expected value or the true value of the public good valuation for country i. Thus, (4) describes the equilibrium outcome for the four possible information situations 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 $E(\alpha_1) < E(\alpha_2)$.[10] 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 types, the strategic considerations are strongest if

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

i.e. the expected value of a country i lies between the two potential valuations of the other country.[11] We will proceed in two steps. First, we determine the best response of a country to a given pure strategy of its opponent. (Recall that $\pi_i = 1$ implies that i will uncover its true valuation with probability 1.) Second, we determine the *value of information* and characterize the set of equilibria for the two-stage game.

[9] The case $w_i < \max\{\Gamma(A_1), \Gamma(A_2)\}$ is also straightforward. 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.

[10] If types are drawn independently from a CDF F and hence $E(\alpha_1) = E(\alpha_2)$, we have to select an equilibrium of the contribution stage when countries have the same (expected) valuation. Focusing on the symmetric equilibrium, the exposition is similar to the asymmetric case without producing crucial differences.

[11] 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.

One-sided information acquisition. First of all, consider the best response of a country to the opponent choosing to remain uninformed. Observe that due to $E(\alpha_1) < E(\alpha_2)$, only country 2 will contribute to the public good if both countries remain uninformed.

Country 1. Suppose $\pi_2 = 0$. With (4) and (5), it follows that equilibrium contributions are $g_1^* = \Gamma(h_1)$ and $g_2^* = 0$ if country 1 uncovers a high value. Otherwise, if country 1 is informed of a low valuation, $g_1^* = 0$ and $g_2^* = \Gamma(m_2)$. Therefore, expected payoff conditional on π_1 and prior to the observation of the signal is equal to

$$\begin{aligned} EU_1(\pi_1|\pi_2 = 0) &= (1-\pi_1)\{w_1 + m_1\varphi(\Gamma_{m_2})\} \\ &\quad +\pi_1\{(1-p_1)[w_1 + l_1\varphi(\Gamma_{m_2})] \\ &\quad\;\; + p_1[w_1 - \Gamma_{h_1} + h_1\varphi(\Gamma_{h_1})]\}. \end{aligned} \tag{6}$$

The first term in (6) describes country 1's expected payoff if, in stage 2, it is uninformed, and the second term distinguishes between the possible outcomes in case of information acquisition of country 1. $\pi_1^* = 1$ if and only if the derivative of (6) with respect to π_1,

$$\Delta_1^{\pi_2=0} := \frac{\partial EU_1(\pi_1|\pi_2 = 0)}{\partial \pi_1} = p_1[h_1\varphi(\Gamma_{h_1}) - \Gamma_{h_1} - h_1\varphi(\Gamma_{m_2})] \tag{7}$$

is positive (since (6) is linear in π_1). Therefore, $\Delta_1^{\pi_2=0}$ is equal to the *value of information* of country 1 given $\pi_2 = 0$,

$$\Delta_1^{\pi_2=0} \equiv EU_1(\pi_1 = 1|\pi_2 = 0) - EU_1(\pi_1 = 0|\pi_2 = 0).$$

Let us examine $\Delta_1^{\pi_2=0}$ more closely. With probability $1-p_1$, neither the supply of the public good nor country 1's contribution change. With probability p_1, country 1 has to pay for the provision of the public good. However, it can adjust the supply of the public good to its individually optimal quantity. 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 ($\lim_{h_1 \downarrow m_2} \Delta_1^{\pi_2=0} = -\Gamma_{h_1} < 0$);

(ii) *increasing and convex in* h_1.

Define a threshold $\hat{h} > m_2$ such that $\hat{h}\varphi\left(\Gamma_{\hat{h}}\right) - \Gamma_{\hat{h}} - \hat{h}\varphi\left(\Gamma_{m_2}\right) = 0$. From Observation 1, it follows that country 1's best response to $\pi_2 = 0$ is to acquire information if and only if $h_1 > \hat{h}$.[12]

Country 2. Equivalent to the case of country 1, if $\pi_2 > 0$, country 2's expected payoff depends on the realization of the signal about its valuation,

$$\begin{aligned} EU_2\left(\pi_2|\pi_1 = 0\right) &= (1-\pi_2)\left\{w_2 - \Gamma_{m_2} + m_2\varphi\left(\Gamma_{m_2}\right)\right\} \\ &\quad +\pi_2\{(1-p_2)\left[w_2 + l_2\varphi\left(\Gamma_{m_1}\right)\right] \\ &\quad + p_2\left[w_2 - \Gamma_{h_2} + h_2\varphi\left(\Gamma_{h_2}\right)\right]\}. \end{aligned} \tag{8}$$

Differentiating (8) with respect to π_2 yields

$$\begin{aligned} \Delta_2^{\pi_1=0} \quad : \quad &= (1-p_2)\left[l_2\varphi\left(\Gamma_{m_1}\right) - \left(l_2\varphi\left(\Gamma_{m_2}\right) - \Gamma_{m_2}\right)\right] \\ &\quad + p_2\left[\left(h_2\varphi\left(\Gamma_{h_2}\right) - \Gamma_{h_2}\right) - \left(h_2\varphi\left(\Gamma_{m_2}\right) - \Gamma_{m_2}\right)\right]. \end{aligned} \tag{9}$$

Together with Observation 1, examination of the sign of (9) leads to the following result.

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 $\Delta_1^{\pi_2=0} > 0$.*

Proof. Iff $\Delta_1^{\pi_2=0} > 0$, country 1 can increase its expected payoff by increasing π_1. This shows (ii). Part (i) is true since (9) is positive for all (m_1, p_2, l_2, h_2) satisfying (5). This follows from monotonicity of φ and an optimality argument: if A_2 denotes the (expected) type of country 2, by definition of Γ,

$$A_2\varphi\left(\Gamma\left(A_2\right)\right) - \Gamma\left(A_2\right) > A_2\varphi\left(\Gamma\left(k\right)\right) - \Gamma\left(k\right) \quad \text{for all } k \neq A_2. \tag{10}$$

Hence, the second term in (9) is positive. The first term is larger than $\left[\left(l_2\varphi\left(\Gamma_{m_1}\right) - \Gamma_{m_1}\right) - \left(l_2\varphi\left(\Gamma_{m_2}\right) - \Gamma_{m_2}\right)\right]$ which is positive since $l_2 < m_1 < m_2$ and $l_2\varphi(G) - G$ is strictly decreasing in G for all $G > \Gamma_{l_2}$. ■

[12] Note that this threshold only depends on $E(\alpha_2)$. Therefore, for a general probability distribution, this result carries over to a similar condition which depends on the mass of types $\alpha_1 > \hat{h}$ compared to types $\alpha_1 \in \left(m_2, \hat{h}\right)$.

Without direct cost of information, there is no equilibrium where both countries do not acquire information ($\pi_1 = \pi_2 = 0$). Lemma 1 already determines the equilibrium strategies in a situation where only one country would have the possibility of investing in information about its benefit of the mitigation of global warming. (Alternatively, this situation could arise if one country's cost of information were very high.) Furthermore, Lemma 1 applies when one country's valuation, i.e. its cost of global warming, is publicly known.

In the one-sided decision problem, country 2 always prefers to learn its valuation. Obviously, it cannot be worse off, since, without additional information, the other country contributes zero in the second stage. However, if it did receive a high signal, it would be able to improve its own contribution. This *adjustment effect* increases its payoff. Learning a low valuation would even shift the full burden of provision to the other country. We refer to this effect as a *strategic effect*. Both effects increase the payoff of country 2. Contrarily, if country 1 reveals a high valuation, its opponent reduces its contribution to zero. In particular, if h_1 is only slightly larger than m_2, country 1 has an incentive to remain uninformed due to this negative strategic effect. 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 gain from the adjustment of the own contribution dominates the negative strategic effect.

Best response to information acquisition. Now suppose that $\pi_j = 1$ and consider a country i's expected payoff dependent on π_i. Here, it is crucial to distinguish whether its potential valuations h_i and l_i are larger or smaller than h_j and l_j, respectively.[13]

Case A: $l_i < l_j,\ h_i < h_j$

Let us first analyze the decision of a country i whose potential valuations are lower than the other country's valuations. Figure 1 illustrates the marginal benefit of the public good supply ($\alpha\varphi'(G)$) dependent on the potential valuations α_i and α_j. A country's stand-alone supply is then determined such that this marginal benefit is equal to the marginal contribution cost (which is constant). From these quantities, the equilibrium contributions for the

[13]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.

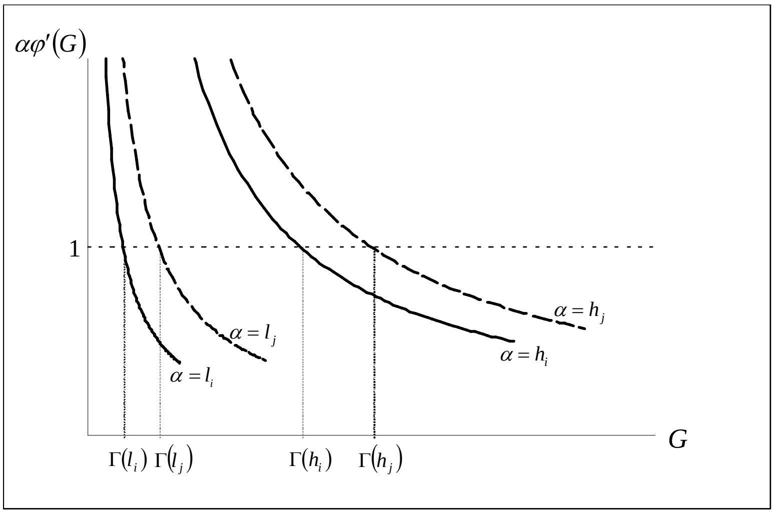

Figure 1: Best response to $\pi_j = 1$: Case A

potential outcomes of the information acquisition can be deduced. Expected payoff $EU_i\left(\pi_i \mid \pi_j = 1\right)$ is equal to

$$\begin{aligned}
&(1-\pi_i)\left\{(1-p_j)\left[w_i - \Gamma_{m_i} + m_i\varphi\left(\Gamma_{m_i}\right)\right] + p_j\left[w_i + m_i\varphi\left(\Gamma_{h_j}\right)\right]\right\} \\
&+ \pi_i\{(1-p_i)(1-p_j)\left[w_i + l_i\varphi\left(\Gamma_{l_j}\right)\right] + (1-p_i)p_j\left[w_i + l_i\varphi\left(\Gamma_{h_j}\right)\right] \\
&\quad + p_i(1-p_j)\left[w_i - \Gamma_{h_i} + h_i\varphi\left(\Gamma_{h_i}\right)\right] + p_ip_j\left[w_i + h_i\varphi\left(\Gamma_{h_j}\right)\right]\}. \qquad (11)
\end{aligned}$$

In order to determine the optimal choice of π_i, i has to take into account the possible outcomes of the information acquisition (drawing on the probabilities p_i and p_j). Deriving (11) with respect to π_i yields

$$\begin{aligned}
\Delta_{i;h_i<h_j}^{\pi_j=1} \quad : &= (1-p_i)(1-p_j)\left[l_i\varphi\left(\Gamma_{l_j}\right) - \left(l_i\varphi\left(\Gamma_{m_i}\right) - \Gamma_{m_i}\right)\right] \\
&\quad + p_i(1-p_j)\left[\left(h_i\varphi\left(\Gamma_{h_i}\right) - \Gamma_{h_i}\right) - \left(h_i\varphi\left(\Gamma_{m_i}\right) - \Gamma_{m_i}\right)\right] \quad (12)
\end{aligned}$$

which, using the same optimality argument as in the proof of Lemma 1(i), is strictly larger than zero. Hence, if $h_i < h_j$, country i's best response to $\pi_j = 1$ is to increase π_i up to 1. 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 the stage 1 decision of i. If $\alpha_j = l_j$, country i pays for the provision if it chooses not to learn its type. Therefore, it is better off by uncovering its value, since, with probability p_i, it is able to adjust the

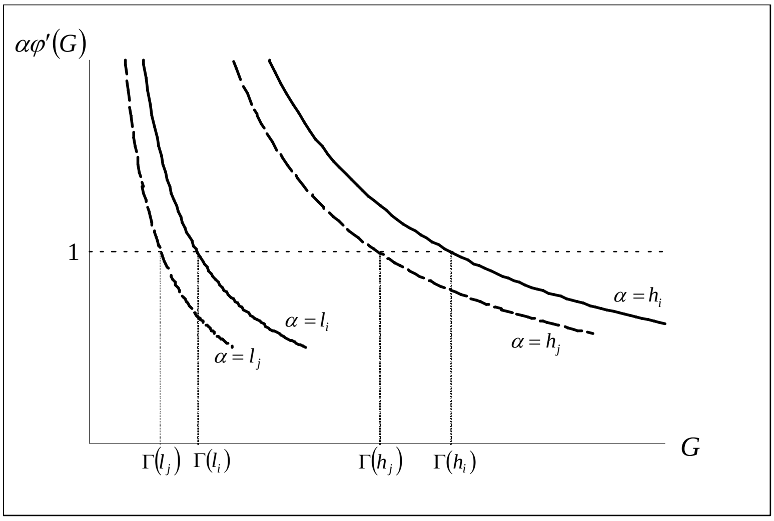

Figure 2: Best response to $\pi_j = 1$: Case B

supply of the public good to Γ_{h_i}, and with probability $1 - p_i$, the opponent will provide the public good.[14]

Case B: $l_i > l_j,\ h_i > h_j$

Now turn to the case where country i's possible valuations are higher than l_j and h_j, respectively. (Figure 2 illustrates the stand-alone supply resulting from the assumption on the location of the potential valuations.) The value of information for $\pi_j = 1$ is given by

$$\begin{aligned} \Delta_{i;h_i>h_j}^{\pi_j=1} \quad : \quad &= (1-p_i)(1-p_j)\left[(l_i\varphi(\Gamma_{l_i}) - \Gamma_{l_i}) - (l_i\varphi(\Gamma_{m_i}) - \Gamma_{m_i})\right] \\ &+ p_i(1-p_j)\left[(h_i\varphi(\Gamma_{h_i}) - \Gamma_{h_i}) - (h_i\varphi(\Gamma_{m_i}) - \Gamma_{m_i})\right] \\ &+ p_i p_j\left[h_i\varphi(\Gamma_{h_i}) - \Gamma_{h_i} - h_i\varphi(\Gamma_{h_j})\right]. \qquad (13) \end{aligned}$$

The first two summands are positive: if the other country has a low value, additional information always improves the individual contribution.[15] However, the third summand can be negative: if country j has a high valuation,

[14] 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 reduction of its contribution from Γ_{m_i} to Γ_{l_i}.

[15] If $l_i < l_j$, $\Delta_{i;h_i>h_j}^{\pi_j=1}$ increases by $(1-p_i)(1-p_j)\left[\Gamma_{l_i} + l_i\varphi(\Gamma_{l_j}) - l_i\varphi(\Gamma_{l_i})\right] > 0$. The following arguments are still valid.

country i may want to avoid to uncover a high valuation itself. Comparative statics analysis shows the following:

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

(i) *decreases in p_j;*

(ii) *increases in h_i and decreases in l_i*

($\lim_{h_i \downarrow m_i, l_i \uparrow m_i,\ h_i > h_j} \Delta_{i;h_i>h_j}^{\pi_j=1} = -p_i p_j \Gamma_{m_i} < 0$).

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 diminishes. Moreover, if the difference between h_i and l_i is sufficiently small, potential gains from an adjustment of the individual contribution are limited, and country i's value of information is negative: the negative strategic effect outweighs the increase in the payoff in case of $\alpha_j = l_j$. But, as in the one-sided information decision of country 1, there exists a critical threshold $\check{h} > h_j$ such that the third summand in (13) is positive iff $h_i > \check{h}$. Hence, $h_i > \check{h}$ is a sufficient condition for $\Delta_{i;h_i>h_j}^{\pi_j=1} > 0$.

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. The following proposition then describes equilibrium play in stage 1. (Equilibrium contributions conditional on the history of the game up to stage 2 are characterized in (4).)

Proposition 1 *Suppose that $E(\alpha_1) < E(\alpha_2)$ and (5) holds.*

Case 1 *If $h_1 > h_2$, in the unique equilibrium, country 2 acquires information; country 1 invests in information if and only if $\Delta_{1;h_1>h_2}^{\pi_2=1} > 0$.*

Case 2 *If $h_1 < h_2$ and*

(a) *$\Delta_{2;h_2>h_1}^{\pi_1=1} > 0$, in the unique equilibrium both country uncover their value;*

(b) *$\Delta_{2;h_2>h_1}^{\pi_1=1} < 0$: If $\Delta_1^{\pi_2=0} > 0$, there is a unique equilibrium where in stage 1 only country 1 uncovers its value and country 2 remains uninformed. Otherwise, if $\Delta_1^{\pi_2=0} < 0$, the unique equilibrium involves mixed strategies and $\pi_1^* = \frac{\Delta_2^{\pi_1=0}}{\Delta_2^{\pi_1=0} - \Delta_{2;h_2>h_1}^{\pi_1=1}}$, $\pi_2^* = \frac{-\Delta_1^{\pi_2=0}}{-\Delta_1^{\pi_2=0} + \Delta_{1;h_1<h_2}^{\pi_2=1}}$.*

For the proof, we refer to the appendix. Case 2 is summarized in the following table.

$h_1 < h_2$	$\Delta^{\pi_1=1}_{2;h_1<h_2} > 0$	$\Delta^{\pi_1=1}_{2;h_1<h_2} < 0$
$\Delta^{\pi_2=0}_{1;h_1<h_2} > 0$	$(\pi_1^* = 1\ ,\ \pi_2^* = 1)$	$(\pi_1^* = 1\ ,\ \pi_2^* = 0)$
$\Delta^{\pi_2=0}_{1;h_1<h_2} < 0$	$(\pi_1^* = 1\ ,\ \pi_2^* = 1)$	*mixed*

Table 1: Equilibrium play in stage 1 (Case 2)

The equilibrium of the two-stage game is unique. As the above analysis shows, it crucially depends on the underlying probability distributions F_1 and F_2, i.e. on the potential valuations and on the probabilities of the different outcomes. Further specification of some of these values will determine which of the two effects of information acquisition prevails. Note that $\Delta^{\pi_j=1}_{i;h_i>h_j} < 0$ is a necessary and sufficient condition for country i (with $h_i > h_j$) to remain uninformed with positive probability.

Proposition 1 points out that the equilibrium may involve the strategic choice of uncertainty of one country. In particular, if the distributions of types are similar, the risk of worsening the own strategic position in the following private provision game may dominate a potential improvement of the own contribution due to information acquisition. The country that then chooses not to uncover its valuation in order to evade the burden of provision is the one whose upper valuation, h, is greater than the upper valuation of the other country. Hence, the country that potentially attaches the largest economic value to CO_2 reductions might decide not to invest in additional information about its true valuation and, as a result, might not contribute to the public good.[16]

Welfare considerations. Proposition 1 states conditions under which in equilibrium at least one country does not acquire information with probability 1. This strategic incentive may lead to additional inefficiencies. From

[16] 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 $\Gamma(h_i) > w_i$ for both $i = 1, 2$. If e.g. $h_1 > h_2$, equilibrium contributions of stage 2 are $g_1^* = w_1$, $g_2^* = \min(w_2, \Gamma_{h_2} - w_1)$. Hence, the country with the strategic disadvantage in the private provision game is still the country with the higher h. However, on the one hand, potential gains from an increase in the supply of the public good are restricted. On the other hand, there is no complete free-riding if both countries uncover a high value. Hence, the impact of these two additional effects on the equilibrium will depend on the particular values of w_1 and w_2.

an ex ante point of view, welfare may be lower than if both countries had chosen to uncover their valuation.

Due to the quasilinearity of the payoff functions, the welfare analysis can concentrate on the aggregate surplus,

$$S(\alpha_1, \alpha_2, G) = \sum_{i=1,2} \alpha_i \varphi(G) - G \; . \tag{14}$$

Thus, the Pareto efficient outcome is equal to $G^0(\alpha_1, \alpha_2) = \Gamma_{\alpha_1+\alpha_2}$. Note that, by assumption, costs of information are zero and do not affect welfare.

A priori, it is not clear whether information acquisition is welfare enhancing. To illustrate the impact of information on welfare, let us first consider the aggregate surplus *ex post*, i.e. depending on the true valuations of the countries. As a benchmark, we compare the two cases where either no country acquires information or both countries acquire information.

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

(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*

$$(l_1 + l_2)\varphi\left(\Gamma_{\max\{l_1,l_2\}}\right) - \Gamma_{\max\{l_1,l_2\}} < (l_1 + l_2)\varphi(\Gamma_{m_2}) - \Gamma_{m_2}. \tag{15}$$

Observation 3 identifies two potential welfare effects of information acquisition. On the one hand, additional information improves the efficiency of the individual contributions. Moreover, 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 supply of the public good is closer to the efficient supply independent of the valuation of the other country, α_j (Observation 3(i)). On the other hand, aggregate surplus can be higher without information acquisition if an uninformed country overcontributes from its point of view. This overcontribution effect may improve efficiency if the true valuation of both countries is low (Observation 3(ii)). A sufficient condition for (15) to be fulfilled is $l_1 + l_2 > m_2$.

Thus, from an *ex ante* point of view, if p_1 and p_2 are sufficiently small, preventing countries from becoming informed could be welfare improving: the chance that the uncertainty over the valuations alleviates the underprovision overcompensates the welfare gain which results from uncovering a high benefit of the mitigation of global warming.[17] However, we can formulate (sufficient) conditions such that a strategic decision to remain uninformed always has a negative impact on welfare, and therefore, a social planner (or supranational institution) would like to induce information acquisition. Under these conditions, the positive effect of information always dominates a potential decrease in welfare as in Observation 3(ii), and the resulting overall effect is independent of the probabilities attached to the potential outcomes.

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

The proof is relegated to the appendix. If the function determining a country's stand-alone quantity is convex in the valuation, the gain from an 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 outcome. It is straightforward to verify that $(C1)$ is fulfilled e.g. for $\varphi(G) = G^{\gamma}$, $0 < \gamma < 1$.

The intuition for $(C1)$ builds on the observation that convexity of $\Gamma(A_i)$ implies convexity of the supply G (because of $G = \max\{\Gamma(A_1), \Gamma(A_2)\}$). 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. This, in turn, increases ex ante welfare. If $(C2)$ holds, the supply of the public good is Pareto efficient if both countries uncover a low value: the overcontribution effect potentially reduces welfare. Thus, under $(C1)$ or $(C2)$, welfare would be highest if both countries uncovered their true valuation. 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 $\varphi(G) = 1 - \exp(-G)$. We get $\Gamma(A_i) = -\ln\left(\frac{1}{A_i}\right)$ if $A_i \geq 1$, and

[17] Note that we still concentrate on (non-cooperative) private provision of the public good. If a social planner could prescribe the contributions of the countries, he would always prefer to uncover the true valuations.

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] In the appendix, we provide an example with concrete parameter values which lead to excessive information acquisition. 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 large 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, being uninformed will then influence in a positive way a country's contribution to the mitigation of global warming.

5 Conclusion

Free-riding behavior may not be the only type of inefficiency that arises in the private provision of public goods. Starting from a standard public goods game, we showed that the strategic choice of information prior to the interaction has a substantial impact on the outcome. An important example for a privately provided public good is the mitigation of global warming. Taking into account decisions about information acquisition gives consideration to the important role of information and uncertainty regarding the country-specific efforts to reduce the emissions of carbon dioxide.

In this paper we have concentrated on the acquisition of information in the context of environmental public goods where the information was related to the idiosyncratic benefit of the mitigation of global warming. We identified conditions under which countries prefer to remain uninformed of their valuation 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

[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.

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 a two-point probability distribution. The two effects of information acquisition identified in this case carry over to a general probability distribution: Additional information leads to an increase in the individual payoff because the own contribution 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 welfare when, in equilibrium, a country decides not to acquire information. Therefore, the provision of information on a supranational level can increase the efficiency of the outcome of the interaction. This result may justify the efforts made by supranational institutions with regard to climate research. But given that these two conditions are violated, welfare could be higher if one country remained uninformed. Too high contributions from the individual point of view that are caused by uncertainty can alleviate the underprovision problem.

A Appendix

A.1 Proof of Proposition 1

Case 1 is immediate because, due to Lemma 1 and $\Delta_{2;h_2<h_1}^{\pi_1=1} > 0$, country 2 has a strictly dominant strategy to uncover its value. (Note that $\Delta_{2;h_2<h_1}^{\pi_1=1}$ refers to (12)). The same holds for Case 2(a). In Case 2(b), if $\Delta_1^{\pi_2=0} > 0$, country 1 has a strictly dominant strategy to uncover its value. Due to $\Delta_{2;h_2>h_1}^{\pi_1=1} < 0$, 2's best response to $\pi_1^* = 1$ is indeed $\pi_2^* = 0$. In these three cases, uniqueness follows from iterated elimination of strictly dominated strategies.

The most interesting case is $\Delta_{2;h_2>h_1}^{\pi_1=1} < 0$ and $\Delta_1^{\pi_2=0} < 0$. First of all, there can be no equilibrium in pure strategies. Intuitively, in stage 1, 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. Thus, consider equilibria in mixed strategies. Country 1 randomizes according to π_1^* if and only if

$$\partial EU_1 \left(\pi \mid \pi_2 = \pi_2^*\right) / \partial \pi = \left(1 - \pi_2^*\right) \Delta_1^{\pi_2=0} + \pi_2^* \Delta_{1;h_1<h_2}^{\pi_2=1} \stackrel{!}{=} 0. \tag{16}$$

(16) is solved uniquely for $\pi_2^* = \left(-\Delta_1^{\pi_2=0}\right) / \left(-\Delta_1^{\pi_2=0} + \Delta_{1;h_1<h_2}^{\pi_2=1}\right)$ which is strictly between 0 and 1. Analogously, $\pi_1^* = \left(\Delta_2^{\pi_1=0}\right) / \left(\Delta_2^{\pi_1=0} - \Delta_{2;h_2>h_1}^{\pi_1=1}\right) \in (0,1)$ in the unique equilibrium.

A.2 Proof of Proposition 2

Note that whenever $\Delta_{i;h_i>h_j}^{\pi_j=1} < 0$, either i remains uninformed or the equilibrium is in mixed strategies. We start with the proof for the first type of equilibrium. The argument carries over to the corresponding outcome of the randomization in the mixed strategy equilibrium. Examine

$$\Delta E[S] := E\left[S\left(\alpha_i, \alpha_j, G\right) | \pi_i = 1, \pi_j = 1\right] - E\left[S\left(\alpha_i, \alpha_j, G\right) | \pi_i = 0, \pi_j = 1\right].$$

With simple transformations, we get

$$\begin{aligned}\Delta E[S] \;=\;& \left(1-p_j\right)\left[\left(1-p_i\right) S\left(l_i, l_j, \Gamma_{\max\{l_i,l_j\}}\right) + p_i S\left(h_i, l_j, \Gamma_{h_i}\right) - S\left(m_i, l_j, \Gamma_{m_i}\right)\right] \\ & + p_i p_j \left[S\left(h_i, h_j, \Gamma_{\max\{h_i,h_j\}}\right) - S\left(h_i, h_j, \Gamma_{h_j}\right)\right]\end{aligned}$$

The second term 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 $S\left(A_i, l_j, \Gamma_{\max\{A_i,l_j\}}\right)$ is convex in A_i. If $A_i > l_j$, deriving $S\left(A_i, l_j, \Gamma_{\max\{A_i,l_j\}}\right)$ with respect to A_i yields

$$\begin{aligned}\frac{\partial S\left(A_i, l_j, \Gamma_{\max\{A_i,l_j\}}\right)}{\partial A_i} &= \varphi\left(\Gamma_{A_i}\right) + \frac{l_j}{A_i}\Gamma'\left(A_i\right), \\ \frac{\partial^2 S\left(A_i, l_j, \Gamma_{\max\{A_i,l_j\}}\right)}{\partial A_i^2} &= \frac{\Gamma'\left(A_i\right)}{A_i}\left(1 - \frac{l_j}{A_i}\right) + \frac{l_j}{A_i}\Gamma''\left(A_i\right).\end{aligned}$$

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

For the mixed strategy equilibrium, it remains to show that under complete information welfare is higher than if *both* countries remained uninformed. Note first that information acquisition of country 1 is always welfare improving if country 2 remains uninformed: learning a low value has no effect on the supply of the public good, but uncovering a high value is welfare enhancing. Set $i = 2$ in the case where only country i remained uninformed. This completes the proof of $(C1)$ for the mixed strategy equilibrium.

$(C2)$ follows directly from Observation 3(i) and the fact that (15) is violated if $\min\{l_1, l_2\} = 0$.

A.3 Proof of Claim 1

Concerning the occurrence of excessive information acquisition, consider as example $\varphi(G) = 1 - \exp(-G)$. We get

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

and hence, $(C1)$ 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 $\Delta_{2;h_2>h_1}^{\pi_1=1} \approx 0.75 > 0$, and both countries acquire information in stage 1. Computation of the expected surplus dependent on π_1 and π_2 yields

$$\begin{aligned} E[S|\pi_1 = \pi_2 = 1] &\approx 5.01, \quad E[S|\pi_1 = 1, \pi_2 = 0] \approx 5.00, \\ E[S|\pi_1 = 0, \pi_2 = 1] &\approx 5.03, \quad E[S|\pi_1 = \pi_2 = 0] \approx 4.85. \end{aligned}$$

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

References

[1] Andreoni, J., 1988. Privately provided public goods in a large economy: the limits of altruism. Journal of Public Economics 35, 57-73.

[2] Andreoni, J., McGuire, M., 1993. Identifying the free riders: a simple algorithm for determining who will contribute to a public good. Journal of Public Economics 51, 447-454.

[3] Bergstrom, T., Blume, L., Varian, H., 1986. On the private provision of public goods. Journal of Public Economics 29, 25-49.

[4] Buchholz, W., Haupt, A., Peters, W., 2005. International environmental agreements and strategic voting. Scandinavian Journal of Economics 107 (1), 175-195.

[5] Buchholz, W., Konrad, K.A., 1994. Global environmental problems and the strategic choice of technology. Journal of Economics – Zeitschrift für Nationalökonomie 60, 299-321.

[6] Buchholz, W., Konrad, K.A., 1995. Strategic transfers and private provision of public goods. Journal of Public Economics 57, 489-505.

[7] Buchholz, W., Nett, L., Peters, W., 1998. The strategic advantage of being less skilled. Economics Letters 60, 35-39.

[8] Caplan, A.J., Ellis, C.J., Silva, E.C.D., 1999. Winners and losers in a world with global warming: noncooperation, altruism, and social welfare. Journal of Environmental Economics and Management 37, 256-271.

[9] Cornes, R., Sandler, T., 1984. Easy riders, joint production, and public goods. Economic Journal 94, 580-598.

[10] Cornes, R., Sandler, T., 1985. The simple analytics of pure public good provision. Economica 52, 103-116.

[11] Fredriksson, P.G., Gaston, N., 2000. Ratification of the 1992 climate change convention: what determines legislative delay? Public Choice 104, 345-368.

[12] Hoel, M., 1991. Global environmental problems: the effects of unilateral actions taken by one country. Journal of Environmental Economics and Management 20, 55-70.

[13] Ihori, T., 1996. International public goods and contribution productivity differentials. Journal of Public Economics 61, 139-154.

[14] Konrad, K.A., 1994. The strategic advantage of being poor: private and public provision of public goods. Economica 61, 79-92.

[15] Konrad, K.A., Lommerud, K.E., 1995. Family policy with noncooperative families. Scandinavian Journal of Economics 97 (4), 581-601.

[16] McGuire, M., 1974. Group size, group homogeneity, and the aggregate provision of a pure public good under Cournot behavior. Public Choice 18, 107-126.

[17] McKibbin, W.J., Wilcoxen, P.J., 2002. The role of economics in climate change policy. Journal of Economic Perspectives 16 (2), 107-129.

[18] Murdoch, J.C., Sandler, T., 1997. The voluntary provision of a pure public good: the case of reduced CFC emissions and the Montreal Protocol. Journal of Public Economics 63, 331-349.

[19] Murdoch, J.C., Sandler, T., Sargent, K., 1997. A tale of two collectives: sulphur versus nitrogen oxides emission reduction in Europe. Economica 64, 281-301.

[20] Robledo, J.R., 1999. Strategic risk taking when there is a public good to be provided privately. Journal of Public Economics 71, 403-414.

[21] Sandler, T., 1992. Collective action: theory and applications. Ann Arbor: University of Michigan Press.

[22] Sandler, T., Sterbenz, F.P., Posnett, J., 1987. Free riding and uncertainty. European Economic Review 31, 1605-1617.

[23] Sandler, T., 2004. Global collective action. Cambridge: Cambridge University Press.

[24] Stern, N., 2006. The Stern review on the economics of climate change. HM Treasury, UK.

[25] Vicary, S., 1990. Transfers and the weakest-link: an extension of Hirshleifer's analysis. Journal of Public Economics 43, 375-394.

[26] Warr, P.G., 1982. Pareto optimal redistribution and private charity. Journal of Public Economics 19, 131-138.

[27] Warr, P.G., 1983. The private provision of a public good is independent of the distribution of income. Economics Letters 13, 207-211.