# Information and Communication in Public Goods Problems*

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**Abstract**

When can ordinary communication help states with common goals resolve uncertainty and provide international public goods more effectively? Using a series of formal models, I examine how the source of private information in a public goods problem affects the credibility of cheap-talk communication. I find that communication is never effective for states with private information about their overall willingness to contribute—the incentive to misrepresent is too strong. Intelligence sharing, or communication about a signal of how much it will take for a project to succeed, is possible only under limited circumstances. By contrast, when the source of private information is a state's comparative advantage across methods of contribution, communication is often effective at resolving uncertainty. The unifying mechanism behind these results is that communication can help states resolve uncertainty only if a state's private information affects what it wants its partners to do. Common interests among states, while necessary, are not a sufficient condition for states to reveal private information through cheap talk.

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# 1 Introduction

When can ordinary communication help states with common goals resolve uncertainty and provide international public goods more effectively? By "ordinary communication," I mean just talking, with no cost for lying and no way to verify what is said—what Farrell and Rabin (1996) call "cheap talk" and Ramsay (2011) calls "simple diplomacy." Ordinary communication, when it works, is a great way for states to exchange information, since it does not require elaborate institutional arrangements or expensive monitoring schemes. Unfortunately, it does not always work, even among states with common goals. States lie. The goal of this paper is, within the realm of international public goods provision, to separate the situations most conducive to truth-telling from those in which states are likely to lie.

Two structural features of the international system make international public goods provision especially tough. First, the system is anarchical, with no central authority to compel states to cooperate or contribute to public goods (Waltz 1979). Under anarchy, all contributions to joint projects are voluntary. This means international public goods will typically be undersupplied, due to the free-rider problem (Olson 1965; Bergstrom, Blume and Varian 1986). The second structural problem is pervasive uncertainty (Jervis 1976; Fearon 1995). Even when states share a common goal, they may be uncertain of each other's dedication to the project, their capability to contribute, and the information they have about what it will take to succeed. Private information only exacerbates the problems with voluntary public goods provision, leading to an even lower supply (Menezes, Monteiro and Temimi 2001). For international public goods to be supplied efficiently, states must manage uncertainty well.

I examine ordinary communication as a means of managing uncertainty in public goods problems. Though I focus on international cooperation, my theoretical approach draws from the literature on the causes of war. In the standard model of crisis diplomacy, the problem with uncertainty is not just that states have private information—it is that states have incentives to lie, making diplomatic talk ineffective at resolving uncertainty (Fearon 1995). Using formal models of uncertainty and communication in public goods provision, I investigate whether the same kind of incentive to misrepresent arises in international cooperation. This is an important question for institutional theories of cooperation. Reducing uncertainty is supposed to be a key way that international institutions help states achieve common goals (Keohane 1984; Martin 1992). But when states can exchange information through ordinary talk, then institutions are unnecessary, at least for resolving uncertainty. Conversely, the scenarios least conducive to honesty are those in which institutions can play the greatest role in facilitating public goods provision.

The main argument is that the source of uncertainty affects the credibility of ordinary communication in international public goods provision. States are willing to share only some types of information with their partners. I first look at a model in which states have private information about their overall willingness to contribute to the public good. I find that ordinary communication is completely ineffective in this setting—a state cannot credibly reveal any information about its willingness to give. No matter its own willingness, a state always wants its partner to contribute as much as possible. This creates an overwhelming incentive to misrepresent, namely to say whatever gets the other state to contribute the most to the public good.

I next consider private information about the total effort required for the public project to succeed, which can be thought of as intelligence. There is more room for communication here, but only a bit more. Intelligence sharing usually breaks down for the same reasons as communication about willingness to contribute, namely that a country always wants to say whatever gets its partner to give as much as possible, regardless of the truth. However, when the intelligence is specific enough to place a sharp upper bound on the amount of effort necessary for success, credible communication might be possible. If a country is sure it will take only so much to succeed, it has no incentive to trick its partner into contributing above and beyond that threshold.

The last source of private information I consider is a country's comparative advantage across multiple avenues of contribution. In this setting, communication is possible under broad conditions. If there are multiple ways to contribute to the public good, communication no longer just shapes how much the states give, but also which type of contribution they make. A state that is advantaged in one type of contribution may want to reveal that advantage so as to ensure that other states distribute their resources efficiently across other avenues of contribution. Therefore, unlike with the other two sources of private information I consider, there is no need for international institutions or other external impetus to resolve states' uncertainty about comparative advantages in public goods problems.

What is responsible for this variation in the effectiveness of ordinary communication? In the literature on communication in crises, overlapping interests between states are seen as the key to effective diplomacy (Sartori 2002; Kydd 2003; Trager 2010, 2011). For example, Sartori writes that "[C]ommunication through words and other costless signals is more likely when the speaker and the listener have interests in common. If two parties have the same goals, the speaker has an incentive to speak honestly, and the listener has no reason to doubt the speaker's information" (p. 125). I argue that common interest is, at best, an incomplete explanation of what makes ordinary communication effective. To wit, in the models I analyze, the constellation of interests is constant—there is a joint interest in public good provision offset by an individual interest in free-riding—yet the possibility of effective communication varies as the source of uncertainty changes. Instead, the results follow from the principle that communication can be effective *only if a state's private information affects what it wants other states to do*. Farrell and Rabin (1996) call this the self-signaling requirement: states with different information must want different things from their partners. Otherwise, if every "type" of a state wants the same thing, it will always say whatever gets its partners to do that, making ordinary communication incredible.[1] Some confusion about the distinction between this condition and "overlapping interests" is that the two concepts are almost identical in the canonical model of cheap talk (Crawford and Sobel 1982), but not necessarily in other settings.

My findings also contrast with the economics literature on communication in public goods problems. Previous studies have claimed that cheap talk may be an effective tool for resolving uncertainty about how much contributors are willing to give to a public project (Agastya, Menezes and Sengupta 2007; Barbieri 2012). The difference between these models and mine is the type of public goods problem under consideration. They examine discrete public goods games, in which the public good is supplied at full value if and only if the total contribution meets or exceeds a commonly known threshold. The assumption of a discrete good is plausible in economic settings, such as a drive to raise money for a construction project, but less so in international relations. Most often in international projects, the participants do not know exactly how much effort is required to succeed (e.g., in joint military operations), or there is no strict success-failure dichotomy (e.g., in pollution reduction). To capture scenarios like these, I model the public good as continuous rather than discrete. The logic that sustains cheap-talk communication about willingness to contribute in discrete public goods projects no longer applies in a continuous setting,[2] though I do find it applies to some special cases of intelligence

[1] Rare exceptions may arise in games with mixed-strategy equilibria or multi-sided incomplete information (Seidmann 1990).

[2] In a discrete public goods game, there is no benefit to fooling one's partner into giv-

sharing.

I lay out a general model of private information and communication in public goods problems in Section 2. In the three subsequent sections, I consider models of private information about overall willingness to contribute, intelligence about the requirements for success, and comparative advantage across avenues of contribution. I offer concluding remarks in Section 6. The Appendix contains proofs that do not appear in the text, as well as an extension to two-sided incomplete information about willingness to contribute.

# 2 The Model

In this section, I lay out the basic model of public goods provision under uncertainty. Since I am primarily concerned with the model's substantive implications for international relations theory, I set up a strategic environment appropriate for international public goods problems and refer to the actors as countries. Contributions to the public good are voluntary and non-refundable, reflecting states' inability to make contracts under anarchy (Waltz 1979). The actors possess private information that they can reveal to each other only through non-verifiable diplomatic statements, as in workhorse models of international politics (Fearon 1995). And the public good itself is continuous rather than discrete, since important international projects usually do not have an exact threshold for success. Even for projects with a quantitative target, like vaccinating a certain percentage of the population or keeping average temperature increases below a particular amount, the exact cost of success may be unknown in advance. The model would also apply to domestic public goods problems that meet these conditions, but it is best tailored for international problems.

## 2.1 Contribution Game

The model is built around a public goods game, in which two countries individually choose how much effort to contribute a joint project or goal. The players are called country 1 and country 2. In the *contribution game*, each country

ing strictly more than the threshold. Therefore, a player may be indifferent between two cheap-talk messages even though one would induce its partner to give more. Equilibria with influential communication in the discrete models depend crucially on this indifference. In the continuous setting, a contributor is always strictly better off the more its partners give, so the possibility of indifference disappears.

chooses how much effort, denoted $x_i \geq 0$, to devote to producing the public good.[3] Let $X_i = \mathbb{R}_+$ denote the set of feasible contributions for country $i$. The marginal cost of contribution for each country is $c_i > 0$.

The public good may be any goal or accomplishment that benefits both states, and effort is any activity that increases the value of the project at a cost to the contributor. Given the contributions $x_1$ and $x_2$, total public good production is $p(x_1 + x_2)$, where the function $p$ is strictly increasing. I assume that $0 \leq p(x) \leq 1$ for all $x$, allowing for either a deterministic or probabilistic interpretation of the public good. In the deterministic interpretation, partial production is possible (and valuable), with $p(x_1 + x_2)$ representing the proportion of the good that is produced. In the probabilistic interpretation, the project either succeeds or fails, with success more likely the more effort states exert. Success is worth 1, failure is worth 0, and $p(x_1 + x_2)$ is the probability of success. The probabilistic interpretation is important to the analysis of intelligence sharing in Section 4; in the rest of the paper, either interpretation is fine.

A country's payoff depends on how much of the good is produced in total and how much of the effort it individually contributes. Each country's utility function is

$$u_i(x_i, x_j) = p(x_i + x_j) - c_i x_i. \tag{2.1}$$

A country's payoff may be non-monotonic in its own effort, as a higher contribution increases both the production of the good and the individual cost to country $i$. However, a country always benefits from higher contributions by its partner.

## 2.2 Uncertainty and Communication

The main question in this paper is what kinds of information countries can (and cannot) credibly share in public goods problems. To model information sharing, I assume that country 1 receives private information that, before the contribution stage, it can send a cheap-talk message about to country 2. I look at three potential sources of private information: a country's marginal cost of effort, intelligence about the total effort required for success, and a country's comparative advantage among multiple avenues of contribution. I will discuss the specifics of each of these in the sections to come. For now, all

[3] Throughout the paper, generic countries are labeled $i$ and $j$, with the understanding that $i \neq j$.

we need to know is that country 1 has a *type* $t_1$ drawn from the type space $T_1$. Nature draws $t_1$ according to the cumulative distribution function $F_1$, where $F_1$ is common knowledge but only country 1 learns the realized value $t_1$. The value of $t_1$ affects country 1's payoffs and, depending on the type of private information, perhaps country 2's as well.

Communication takes place in a *messaging stage* that occurs after country 1 learns its type but before the contribution stage. In the messaging stage, country 1 selects a message $m_1$ from the message space $M_1$. For ease of exposition, I assume throughout the analysis that the message space and type space are identical: $M_1 = T_1$. Country 1's *messaging strategy* is a function $\mu_1 : T_1 \to M_1$, so $\mu_1(t_1)$ denotes the message sent by the type $t_1$. Messages are cheap talk, as in Crawford and Sobel (1982): each type of country 1 may send any message in $M_1$, and the chosen messages have no direct effect on either country's payoff.

What makes cheap talk important is that country 1's message shapes its partner's beliefs, which in turn may affect its behavior in the contribution stage. For every message $m_1 \in M_1$, let $\lambda_2(m_1)$ be a probability measure on $T_1$ that reflects country 2's beliefs about the value of $t_1$ after receiving the message $m_1$. In the contribution stage, then, country 2's choice of effort depends on the message it has received from country 1. Its contribution strategy is a function $s_2 : M_1 \to X_2$, where $s_2(m_1)$ denotes the amount spent by country 2 after receiving the message $m_1$. Similarly, country 1's contribution strategy is a function of its type and the message it has sent, $s_1 : T_1 \times M_1 \to X_1$, with $s_1(t_1, m_1)$ denoting how much type $t_1$ gives after sending $m_1$.

To summarize, given country 1's messaging strategy $\mu_1$, country 2's belief system $\lambda_2$, and the contribution strategies $s_i$ for each $i = 1, 2$, the sequence of play is as follows:

1. Nature privately informs country 1 of its type, $t_1 \in T_1$.
2. Country 1 sends the message $\mu_1(t_1) \in M_1$.
3. Country 2 updates its beliefs about $t_1$ to $\lambda_2(\mu_1(t_1))$.
4. The countries simultaneously contribute $s_1(t_1, \mu_1(t_1)) \in X_1$ and $s_2(\mu_1(t_1)) \in X_2$ to the public good.
5. The game ends and payoffs are realized.

An *assessment* $\sigma = (\mu_1, s_1, s_2, \lambda_2)$ is a tuple containing both countries' strategies and country 2's belief system.

## 2.3 Solution Concept

As this is a multistage game of incomplete information with observed actions, the appropriate solution concept is perfect Bayesian equilibrium (Fudenberg and Tirole 1991). An assessment is an *equilibrium* if each country's strategy is sequentially rational given its beliefs and the other country's strategy, and beliefs are updated in accordance with Bayes' rule whenever possible.

Equilibria can be classified in terms of how much information is revealed in the messaging stage. At one end of the informational spectrum is a *babbling equilibrium*, in which no meaningful communication takes place because country 1 reveals anything about its type. In a babbling equilibrium, $\mu_1$ is a constant function, so country 1 always sends the same message regardless of its type. At the other extreme is a *fully separating equilibrium*, in which country 1 reveals its exact type: $\mu_1(t_1) = t_1$ for all $t_1$.[4] Any equilibrium that is neither babbling nor fully separating is *partially separating*.

The interesting question is not just what types of information a state might share voluntarily, but when that information sharing can aid international public goods provision. In the language of cheap talk models, an equilibrium in which a state reveals information and that revelation affects the outcome is an *influential equilibrium*. An equilibrium of this model is influential if country 2 contributes different amounts after different messages (on the path of play):

$$s_2(\mu_1(t_1)) \neq s_2(\mu_1(t_1')) \qquad \text{for some } t_1, t_1' \in T_1. \tag{2.2}$$

An immediate consequence of this definition is that a babbling equilibrium cannot be influential. However, not all non-babbling equilibria are influential. For example, an equilibrium in which country 1 fully reveals its type but country 2 always contributes $x_2 = 0$ on the path of play is non-babbling and non-influential.

Influential communication is most likely to break down when every type of country 1 has the same preferences over country 2's actions. In an influential equilibrium, country 1's choice of message effectively dictates what its partner will do. So for different types to choose different messages, they must prefer different actions by country 2—or at least be indifferent. This is exactly why cheap talk fails to help resolve crises in the canonical model of crisis bargaining: every type of the informed country wants to get the highest offer

[4] In general, any one-to-one function $\mu_1$ corresponds to a fully separating messaging strategy; I use the form given here for expository convenience.

possible, regardless of its true resolve (Fearon 1995). It is easy to see the same logic playing out in public goods problems. Suppose that every type of country 1 strictly prefers greater contributions by county 2. Then in an influential strategy profile, every type of country 1 would prefer to deviate to sending whichever message induces the greatest possible contribution by country 2, so there cannot be an influential equilibrium. In the next section, I will show that this exact incentive to misrepresent prevents all influential communication about a country's overall willingness to contribute to a public good. In the subsequent sections, I show why there may be influential communication about other sources of private information—intelligence about the requirements for success and comparative advantage across avenues of contribution. For these, the informed country may vary enough in its preferences over its partner's actions that not every type prefers to send the same message.

## 3 Uncertainty about Willingness to Contribute

An obvious source of uncertainty in international public goods problems is a state's willingness to contribute.[5] The amount of effort a state is willing to spend on a joint goal depends on how highly the state's decision-makers value the project itself relative to the cost of contributing. To some extent this might be common knowledge. For example, in efforts to reduce global carbon emissions, states know that a leader from an environmentalist party will be more willing to contribute than one from a conservative party. But it is natural to imagine there being some residual uncertainty about states' willingness to contribute, whether because the state's political system is not transparent or simply because its leader's exact weighting of priorities and interests is not public.

The results for communication about willingness to contribute are stark. Simply put, a state cannot credibly reveal anything about much it is willing to give. The incentives to misrepresent are too strong. The problem is that a state's own willingness to contribute does not affect its preferences over its partner's actions—every type of state, no matter how willing, wants its partner to give as much as possible. Therefore, influential communication unravels, as every type of the informed country strictly prefers to send whichever message induces the greatest contribution by its partner.

[5] Prior research on private information about willingness to contribute to a public good includes Menezes, Monteiro and Temimi (2001), Agastya, Menezes and Sengupta (2007), Bag and Roy (2011), and Barbieri (2012).

In the game with *uncertainty about costs*, country 1's private information is $c_1$, its marginal cost of effort. Since lower-cost types prefer to give more than higher-cost types, uncertainty about costs can also be thought of as uncertainty about how much a country is willing to contribute. I assume $c_1$ is drawn from a probability distribution whose support is $T_1 \subseteq \mathbb{R}_{++}$. No further structure is needed to obtain the main result, which is that there cannot be any influential communication in the game with uncertainty about costs (Proposition 3.1). The distribution of country 1's type may take any form, and so can the public good production function $p$, as long as it is strictly increasing. For the other result in this section, that uncertainty about country 1's type harms *ex post* contribution totals and social welfare (Proposition 3.2), we have to impose differentiability and concavity on the public good production function.

Without further ado, I formally state the main result for this source of uncertainty, which is that a state cannot credibly reveal any information about its willingness to contribute to an international project.

**Proposition 3.1.** *There is no influential equilibrium in the game with uncertainty about costs.*

*Proof.* In an influential assessment, there are types $c_1, c_1' \in T_1$ such that country 2 contributes more after receiving the message $c_1'$ sends: $s_2(\mu_1(c_1')) > s_2(\mu_1(c_1))$. The type $c_1$ can strictly increase its payoff by sending $\mu_1(c_1')$ in the messaging stage and then contributing the same as if it had sent its prescribed message: under this deviation, more of the public good is produced at the same cost to country 1. Therefore, no influential assessment can be an equilibrium. □

Communication fails not because of a lack of common interests, but because the informed country's preferences about its partner's actions do not vary across types. In the public goods framework modeled here, a country always prefers greater contributions by its partner, regardless of its own marginal cost of effort. All types of the informed country strictly prefer to send whichever message would result in the other country contributing the most, which in turn means that message is not a credible signal. Without this uniformity of preferences across types, influential communication might be possible. For example, suppose that low-cost types of the informed country were lone rangers who would rather contribute all effort on their own than split the burden with their partner. A situation like this, in which the incentive to free-ride is not universal, could arise if a country doubted its partner's competence or if coordinating effort from multiple sources carried transaction costs. In that case, unlike in the typical public goods setting, a low-cost type wants its partner to contribute less and thus has no incentive to feign high costs. But without that kind of variation in preferences across types, a country's diplomatic statements about its willingness to support a joint project cannot be credible and influential.

If cheap talk does not work, then states must engage in costly monitoring or intelligence activities in order to learn about each other. Are these costs worth paying? Would public good provision be higher, or the countries better off, if the informed country's type were revealed? To answer this, I compare the equilibrium of the game with uncertainty to the complete-information benchmark. If both countries' types were common knowledge, in equilibrium the lower-cost country would give as much as it is willing and the higher-cost country would give nothing.[6] This outcome cannot be achieved if there is private information and no communication, as the uninformed country does not know whether its cost of effort exceeds its partner's. At best, the total contribution is no greater than under complete information, albeit possibly distributed inefficiently (i.e., with the higher-cost country contributing part). At worst, the total contribution is strictly less than if types were common knowledge. Therefore, the inability to communicate in the face of uncertainty indeed leaves the countries worse off, as the next result states.[7]

**Proposition 3.2.** *Let the public good production function $p$ be continuously differentiable and strictly concave. In any equilibrium of the game with uncertainty about costs,* ex post *total contributions and social welfare are never greater than if $c_1$ were common knowledge. They are strictly less with positive probability if* $\Pr(c_1 < c_2) > 0$, $\Pr(c_1 > c_2) > 0$, *and* $p'(0) > c_2$.

To sum up the two results, social welfare would be greater if the informed country's cost of contribution were known, but ordinary communication is of no use in bringing it to light. Efficient public goods provision relies on states resolving their uncertainty, but we cannot expect them to do so on their own. This is where institutions can play a role, providing an external impetus for information-sharing in the absence of an internal one (Keohane 1984; Martin 1992). Moreover, the findings provide some direction for how institutions

[6]The Appendix gives a formal statement and proof of this result.

[7]The proof of this result, along with all other proofs not given in the text, appears in the Appendix.

can best serve the cause of efficiency. The socially efficient outcome, as shown in the proof of Proposition 3.2, involves the lower-cost country supplying the public good by itself. Punishing countries for failing to contribute will not lead to the first-best outcome, and in fact may harm efficiency. Instead, an ideal institutional design would focus first on incentivizing honesty about one's willingness to contribute, then on compensating more-willing countries for taking on the bulk of the effort.

# 4 Intelligence Sharing

States may also have asymmetric information about the nature of the joint project itself, including about how much effort it will take to succeed. For example, in a joint military campaign, one state may have better intelligence than its allies about the capabilities of a common enemy. States on a joint mission have the best chances of success and can most efficiently come to a division of labor if they all have the best information possible. On the other hand, it may be in a state's individual interest to exaggerate the enemy's capabilities—or, in broader terms, how much effort is required for a project to succeed—so as to convince its partners to contribute more than they would have if they knew the truth. In this section, I look for conditions under which states can overcome the incentive to exaggerate and share intelligence honestly.

With private information about willingness to give, communication breaks down because the informed country will always say whatever makes its partner contribute as much as possible. For the most part, this incentive to lie holds true for the intelligence-sharing problem too. But there are some interesting exceptions, where honest intelligence sharing is possible. These occur when a country receives intelligence specific enough to place a sharp upper bound on how much effort it will take to succeed. If a country knows its partner will do just enough to assure success, and "just enough" effort is no worse than "too much," then the incentive to exaggerate a threat disappears. So intelligence sharing is less hopeless than getting countries to admit how much they are willing to contribute. Not much less hopeless, though—the conditions for influential communication are fragile, as they break down when we add even a bit of uncertainty.

I examine the intelligence-sharing problem formally by taking the baseline model and interpreting the public good as a joint project with a binary outcome (success or failure). The project succeeds if the total contribution $x_1 + x_2$

exceeds the *threshold* $y \geq 0$, where $y$ is a random variable.[8] Without private information, this is identical to the baseline model, letting the function $p$ be the cumulative distribution function of the threshold $y$.

In the *intelligence-sharing game*, country 1's type is a signal about the threshold necessary for success, denoted $z$. The threshold and the signal are drawn from the joint probability distribution $F_{y,z}$ on $Y \times Z$, where $Z \subseteq Y \subseteq \mathbb{R}_+$. This distribution is common knowledge, but only country 1 observes the realized value of $z$, and neither country observes the realized value of $y$. Since country 1's private information is the value of the signal $z$, its type space is $T_1 = Z$. For each $z \in Z$, let $F_y(\cdot \mid z)$ denote the conditional distribution function of the threshold given the signal. Country 1's interim expected utility function is

$$Eu_1(x_1, x_2 \mid z) = F_y(x_1 + x_2 \mid z) - c_1 x_1, \tag{4.1}$$

and country 2's is

$$Eu_2(x_1, x_2 \mid m_1) = E_{\lambda_2(m_1)}\left[F_y(x_1 + x_2 \mid z)\right] - c_2 x_2. \tag{4.2}$$

In order to focus on the intelligence-sharing problem, I now assume that both countries' marginal costs of contribution are common knowledge.

The incentive problem here is familiar. Each country wants the project to succeed, though with the other country doing as much of the work as possible. So when would the informed country ever refrain from exaggerating the threat, or more generally, saying whatever gets its partner to give the most? When we asked this question in the game with uncertainty about willingness to contribute, the answer was "Never." But there is a subtle difference between this game and that one: in the intelligence-sharing game, if the signal is discriminating enough, the informed country may only *weakly* prefer greater contributions by its partner. For example, imagine that a country learns that a total contribution of $x_1 + x_2 = 1$ will assure success. Then it is indifferent between its partner contributing $x_2 = 1$ or any other amount $x_2 > 1$, as all of them have the same outcome—guaranteed success. Hence there is no incentive to exaggerate, as long as telling the truth gets the partner to contribute at least the amount required for success. The following result formally states the conditions under which the informed country may, in equilibrium, send a message that results in a less-than-maximal contribution by its partner.

[8] On threshold uncertainty in public goods games, see Nitzan and Romano (1990), Suleiman (1997), and McBride (2006).

**Proposition 4.1.** *Consider an equilibrium of the intelligence sharing game, and let $\bar{x}_2$ denote the greatest amount country 2 spends on the equilibrium path. In any subgame on the equilibrium path in which country 2 spends $x_2 < \bar{x}_2$, country 1 spends nothing and believes there is zero probability the threshold lies in $(x_2, \bar{x}_2)$.*

According to this proposition, influential communication can take place only if the intelligence is precise. If revealing the signal would lead to the other country spending $x_2$, it is not enough for the informed country to believe the true threshold is probably below $x_2$. It must be certain. Otherwise, it would strictly prefer to lie and induce its partner to give even more, so as to maximize the chance of success. Influential communication is thus impossible unless the signal is strong enough to rule out some possibilities altogether. By this token, if the informed country's updated beliefs always have full support, influential communication is impossible, as the next result states.

**Corollary 4.2.** *If the support of country 1's updated beliefs includes $[0, \frac{1}{c_2}]$ after every signal $z \in Z$, then there is no influential equilibrium.*

At the other end of the spectrum, if the informed country learns exactly how much it will take to succeed, then full intelligence sharing is possible. Call the signal *perfectly informative* if the random variable $z$ is identical to $y$. If the signal is perfectly informative and the informed country reveals it honestly, then the contribution subgame is simply a complete-information discrete public goods game. This means any contribution scheme whereby $x_1 + x_2 = z$ is an equilibrium if $z \leq \frac{1}{c_1} + \frac{1}{c_2}$, and otherwise $x_1 = x_2 = 0$ is the unique equilibrium. We know from Proposition 4.1 that the equilibrium must entail the informed country free-riding as much as possible, so construct it as follows:

1. If $z \leq \frac{1}{c_2}$, then country 2 contributes $x_2 = z$ and country 1 contributes nothing.
2. If $\frac{1}{c_2} < z \leq \frac{1}{c_1} + \frac{1}{c_2}$, then country 2 contributes $x_2 = \frac{1}{c_2}$, the most it is willing, and country 1 contributes the remainder, $x_1 = z - \frac{1}{c_2}$.
3. If $z > \frac{1}{c_1} + \frac{1}{c_2}$, then both countries contribute nothing.

Under this contribution scheme, which is illustrated in Figure 1, country 1 has no incentive to lie in the messaging stage. In the first case, it gets success at no cost, its first-best outcome. In the second, there is no other message that would

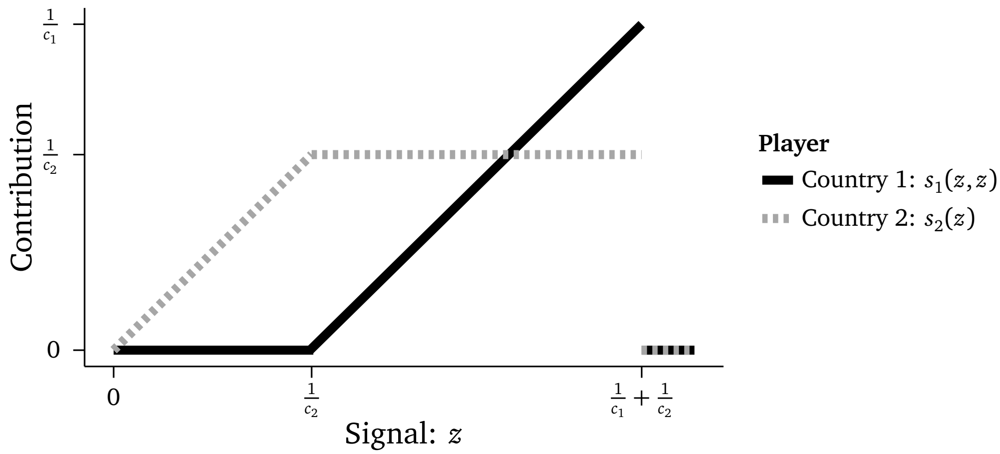


**Figure 1.** Contributions by each country on the path of play in a fully separating equilibrium of the intelligence-sharing game when the signal is perfectly informative.

get country 2 to give more and thus no profitable deviation. In the third, even if country 2 gave all it were willing, country 1 would not be willing to make up the difference and the outcome would still be failure. Honest revelation is therefore an equilibrium strategy if intelligence is exact, as stated in the following result.

**Proposition 4.3.** *If the signal is perfectly informative, then there is a fully separating, influential equilibrium of the intelligence-sharing game.*

Looking at these results in combination, one apparent conclusion is that intelligence sharing is more likely to be successful the more precise the intelligence is. Whether this is true depends on the definition of precision. If there is so much uncertainty about the prerequisites for success that no contingency can be ruled out, amplifying the signal relative to the noise has no effect on the chances of honest communication—it is impossible either way. But when the intelligence is good enough to place bounds on the possible thresholds for success, narrower bounds are better. The plausibility of gathering such specific intelligence depends on the nature of the joint undertaking. For example, if the project is to take out all of a state's nuclear facilities but the number of sites is unknown in advance, it is conceivable that intelligence could yield a specific range of possibilities. In cases with a specific numerical target like this one, the key to voluntary intelligence sharing is simply to get the best intelligence. On the other hand, for a more amorphous project like the overthrow of a government or even victory in a particular battle, it is hard to imagine what findings could place sharp bounds on how much effort it would take to succeed. For these kinds of projects, the incentive to exaggerate is too great for unverifiable voluntary intelligence sharing to work. States would be best off pursuing institutional or technical solutions, such as NATO members did in establishing an Intelligence Fusion Center to directly integrate their systems for gathering and disseminating information (Mitchell 2007).

Another interesting conclusion is that norms of burden sharing can undermine intelligence sharing. In an influential equilibrium, the informed country must sometimes tell the truth even when lying would result in its partner contributing more. This cannot be incentive-compatible unless the partner supplies all of the effort in this cases, as stated in Proposition 4.1. Otherwise, the informed country would prefer to lie and reduce its own contribution. So if the countries have a prior commitment to a fair contribution scheme, in which each must contribute some fixed proportion of the total effort, intelligence sharing becomes impossible. A country cannot credibly reveal intelligence unless its partner is at least sometimes willing to do all the work.

## 5 Uncertainty about Comparative Advantage

To study one last source of incomplete information, I relax the assumption that there is only one way for states to contribute to the joint project. In real-life public goods problems in the international arena, states can give support in multiple ways. Examples abound: The fight against global warming depends on reductions in various greenhouse gases, including both carbon dioxide and methane. Global public health programs require the manufacture of supplies (e.g., vaccinations), distribution of those supplies to affected populations, and education and outreach efforts. Contemporary military interventions usually require both ground troops and air support. Not only may states differ in their willingness or ability to supply various methods of contribution, but they may also be uncertain about each other's relative advantages. In this section, I modify the model to allow for two means of contribution and cross-country differences in the cost of each method, and I assume that one country has private information about which method it can provide more efficiently. In contrast to the earlier results, influential communication about comparative advantage is possible under broad conditions.

When there is more than one way to contribute, a country does not necessarily always want the same thing from its partner—and that is precisely why communication is effective here. To see why, think about a military venture that requires ground forces and air power to succeed. A country with an excellent infantry may prefer for its partner to focus on the air war, whereas a country that specializes in air power may want its partner to supply the ground troops. Therefore, a country with private information about its specialty might have an incentive to be honest with its partner, so as to induce it to cooperate the right way. Trager (2011) presents a similar finding about multidimensional bargaining between adversaries.

I study communication about comparative advantage by extending the baseline model to have two means of contribution to the public good. In the *two-method game*, public good provision depends on two dimensions of effort, denoted $A$ and $B$. In the contribution stage, each state chooses whether to devote effort to each of the two avenues of contribution. To keep the analysis simple, I assume the decision to contribute to each method is dichotomous, so each state's action is a pair $x_i = (c_i^A, x_i^B)$ of binary decisions.[9] Each country's action space is $X_i = \{0, 1\}^2$. The cost to country $i$ of participating in method $A$ is $\alpha_i$, and its cost of method $B$ is $\beta_i$. The probability of success is now a function of the total contribution to each method, denoted $p(x^A, x^B)$, which is strictly increasing in both arguments. A country's utility function in the two-method contribution game is

$$u_i(x_i, x_j) = p(x_i^A + x_j^A, x_i^B + x_j^B) - \alpha_i x_i^A - \beta_i x_i^B. \tag{5.1}$$

Figure 2 contains the payoff matrix for the contribution game.

I assume the source of uncertainty is country 1's cost of contributing to method $B$. Country 1's type is $\beta_1$, drawn from the type space $T_1 = \{\beta_1^L, \beta_1^H\}$. It equals $\beta_1^L$ with probability $\pi \in (0, 1)$ and $\beta^H$ with probability $1-\pi$, where $\beta_1^L < \alpha_1 < \beta_1^H$. I call country 1 "$B$-advantaged" if $\beta_1 = \beta_1^L$ and "$A$-advantaged" if $\beta_1 = \beta_1^H$. The prior distribution of $\beta_1$ is common knowledge, but only country 1 observes its realized value. The other cost parameters, $\alpha_1$, $\alpha_2$, and $\beta_2$, are common knowledge. I assume it is never in a state's interest to contribute to a

[9]The main finding here—that an influential equilibrium exists in a nontrivial subset of the parameter space—would still hold if the action space were continuous.

| | | Country 2 | | | |
|---|---|---|---|---|---|
| | | $(0,0)$ | $(1,0)$ | $(0,1)$ | $(1,1)$ |
| Country 1 | $(0,0)$ | $p(0,0)$<br>$p(0,0)$ | $p(1,0)$<br>$p(1,0)-\alpha_2$ | $p(0,1)$<br>$p(0,1)-\beta_2$ | $p(1,1)$<br>$p(1,1)-\alpha_2-\beta_2$ |
| | $(1,0)$ | $p(1,0)-\alpha_1$<br>$p(1,0)$ | $p(2,0)-\alpha_1$<br>$p(2,0)-\alpha_2$ | $p(1,1)-\alpha_1$<br>$p(1,1)-\beta_2$ | $p(2,1)-\alpha_1$<br>$p(2,1)-\alpha_2-\beta_2$ |
| | $(0,1)$ | $p(0,1)-\beta_1$<br>$p(0,1)$ | $p(1,1)-\beta_1$<br>$p(1,1)-\alpha_2$ | $p(0,2)-\beta_1$<br>$p(0,2)-\beta_2$ | $p(1,2)-\beta_1$<br>$p(1,2)-\alpha_2-\beta_2$ |
| | $(1,1)$ | $p(1,1)-\alpha_1-\beta_1$<br>$p(1,1)$ | $p(2,1)-\alpha_1-\beta_1$<br>$p(2,1)-\alpha_2$ | $p(1,2)-\alpha_1-\beta_1$<br>$p(1,2)-\beta_2$ | $p(2,2)-\alpha_1-\beta_1$<br>$p(2,2)-\alpha_2-\beta_2$ |

**Figure 2.** Payoff matrix for the contribution stage of the two-method game.

method that its partner is also contributing to.[10] This condition is equivalent to

$$p(2,x^B)-p(1,x^B)\le \min\{\alpha_1,\alpha_2\} \quad \text{for all } x^B=0,1,2,$$
$$p(x^A,2)-p(x^A,1)\le \min\{\beta_1^L,\beta_2\} \quad \text{for all } x^A=0,1,2.$$

I look for a type of equilibrium in which the two countries coordinate on a natural division of labor: country 1 contributes to whichever method it is advantaged in, and country 2 takes up the other. Reaching such a division of labor requires that country 1 honestly reveal its type. A *division of labor equilibrium* is thus an equilibrium in which:

1. Country 1 honestly reveals its type in the messaging stage.
2. If country 1 is $A$-advantaged, country 1 contributes $(x_1^A,x_1^B)=(1,0)$ and country 2 contributes $(x_2^A,x_2^B)=(0,1)$.
3. If country 1 is $B$-advantaged, country 1 contributes $(x_1^A,x_1^B)=(0,1)$ and country 2 contributes $(x_2^A,x_2^B)=(1,0)$.

In a division of labor equilibrium, the total contribution along the path of play is always $(x^A,x^B)=(1,1)$. A division of labor equilibrium is influential by definition, though other types of influential equilibria may also exist.[11]

[10] Influential equilibria would still exist if this condition were relaxed, though the statement of the conditions for Proposition 5.1 would become more cumbersome.

[11] Any influential equilibrium must entail country 2 choosing $x_2=(1,0)$ in response to one message and $x_2=(0,1)$ in response to the other.

In order to delineate the conditions under which there is a division of labor equilibrium, it is useful to think of country 1's messages as statements about what it will do in the contribution stage. Consider the $B$-advantaged type's message, which can be interpreted as the statement "I will contribute to method $B$." Farrell and Rabin (1996) delineate two requirements for a statement like this to be credible, namely that it be *self-committing* and *self-signaling*. A statement is self-committing if the speaker prefers to do what it promises, given how its partner will behave if it believes the promise. In a division of labor equilibrium, that means a $B$-advantaged type prefers to contribute to method $B$ when it expects its partner to give to method $A$. Similarly, a statement is self-signaling if a speaker wants it to be believed if and only if it is true. In the current example, the $B$-advantaged type sends a self-signaling message if it would rather its partner believe it is $B$-advantaged (and thus contribute to method $A$) than believe it is $A$-advantaged (and thus contribute to method $B$). The following proposition summarizes the conditions under which both the self-commitment and self-signaling requirements are satisfied, and therefore a division of labor equilibrium exists. In particular, there is a division of labor equilibrium as long as the marginal effect of each type of contribution on the value of the public good (or the chance of success) is sufficiently large.

**Proposition 5.1.** *In the two-method game, there exists a division of labor equilibrium if the following inequalities are satisfied:*

$$p(1,1) - p(0,1) \geq \max\left\{\alpha_1, \alpha_2, \beta_1^L\right\}, \tag{5.2}$$

$$p(1,1) - p(1,0) \geq \max\left\{\alpha_1, \beta_1^L, \beta_2\right\}. \tag{5.3}$$

The incentive to misrepresent that impeded communication in prior forms of the model does not show up here, as the informed country's comparative advantage dictates what it wants from its partner. When the conditions of the proposition hold, the $A$-advantaged type wants its partner to contribute to $B$, and the $B$-advantaged type wants its partner to contribute to $A$. Therefore, neither type has an incentive to mimic the other. The result suggests that uncertainty about comparative advantages across contribution methods should not be a major hindrance to international public goods provision, even when there is no institution in place to manage information. As long as each avenue of contribution is reasonably effective, it is in every state's interest to be honest with its partners about what it is best at. Ordinary diplomatic talk is thus an effective means of coordinating the division of labor across multiple avenues of contribution to a joint project.

## 6 Conclusion

I have analyzed the role of communication in international public goods problems. The main finding is that ordinary communication can be effective only when there is a relationship between a country's private information and what it wants its partners to do. This condition is satisfied for some sources of private information but not others, creating variation in the possibility of effective communication. The biggest risk for communication to break down is for all types of states to prefer that their partners give as much as possible, creating an incentive to misrepresent. These findings buttress institutionalist claims that formal organizations—or other means of un-cheapening diplomatic talk—are necessary to reduce uncertainty in at least some international public goods dilemmas. The results also call into question the claim that ordinary communication can be effective as long as states have shared interests, as previous studies of diplomatic credibility have claimed.

In light of this paper's findings, how can states with common goals best achieve them despite pervasive uncertainty? I have already suggested that that institutional regimes should focus on dishonesty rather than failure to contribute, as the most efficient solution to a public goods problem may entail some free-riding. Besides using the punishment strategies typically advocated in the literature on international cooperation (Axelrod 1984; Keohane 1984), international institutions might benefit from implementing the kinds of schemes explored in the economics literature on uncertainty and public goods. Institutions with sufficient budgetary resources may be able to coordinate the types of efficient transfer schemes identified by mechanism design theorists (d'Aspremont and Gérard-Varet 1979). Short of that, international organizations may be able to increase public goods provision by establishing routines for sequential giving and by publicizing early contributions (Bag and Roy 2011; Barbieri 2012). Institutions can even improve global welfare simply by drawing more states into the pool of contributors when new problems arise (Bliss and Nalebuff 1984). These strategies for managing asymmetric information in joint projects may be useful as complements or substitutes to the kind of "tit-for-tat" punishments usually discussed in the international institutions literature. A direction for future research would be to design revelation schemes when states have asymmetric intelligence information, which has received much less attention in the mechanism design literature than uncertainty about costs of contribution.

This paper's findings also highlight the need for a more robust body of theory on the role of ordinary communication in international politics. Besides the notion that communication is effective when states have common interests—a claim that this paper's findings contradict—we have little sense of what kinds of information are exchanged diplomatically or what types of problems diplomacy is best at solving. One particularly important question that remains open is what role communication plays in the formation of coalitions among states. Shifts in international allegiances over time are a major topic of diplomatic history, but existing theories of diplomatic talk only consider relations between pairs of states who know the broad contours of each other's preferences. Future work on diplomatic communication should consider how states discover their friends and enemies in a world of many actors.

# A Appendix

## A.1 Proofs of Stated Results

This section contains the proofs of results stated in the body of the paper.

### A.1.1 Uncertainty about Willingness to Contribute

To prove the welfare result, Proposition 3.2, we first need some results on the complete-information equilibrium when the public good production function is continuously differentiable and strictly concave. In this setting, a country with marginal cost $c$ has a unique *stand-alone contribution*—the amount it would give if it were the only player in the game—given by

$$x^*(c) = \begin{cases} (p')^{-1}(c) & c < p'(0), \\ 0 & c \geq p'(0). \end{cases} \tag{A.1}$$

When costs are complete information, in equilibrium the country with the lower marginal cost gives its stand-alone contribution and the other gives nothing.

**Lemma A.1.** *Let the public good production function $p$ be continuously differentiable and strictly concave, and suppose the marginal contribution costs $c_1$ and $c_2$ are common knowledge. If $c_1 < c_2$, the unique Nash equilibrium of the contribution game is $(x_1, x_2) = (x^*(c_1), 0)$. If $c_1 > c_2$, the unique Nash equilibrium of the* *contribution game is* $(x_1, x_2) = (0, x^*(c_2))$*. If* $c_1 = c_2 = c$*, then* $(x_1, x_2)$ *is a Nash equilibrium of the contribution game if and only if* $x_1 + x_2 = x^*(c)$*.*

*Proof.* I begin by ruling out mixed-strategy equilibria. Fix country $j$'s strategy as a mixed strategy given by the probability measure $\xi$. As $p$ is strictly concave, country $i$'s objective function,

$$Eu_i(x_i) = \int_{X_j} p(x_i + x_j)\, d\xi - c_i x_i,$$

is strictly concave as well (Hildreth 1974). This implies any country has a unique best response to any mixed strategy by its partner, so there can be no mixed-strategy equilibrium. A further consequence of strict concavity of the objective function is that the pure strategy profile $(x_1, x_2)$ is an equilibrium if and only if the first-order optimality conditions

$$\begin{aligned} &x_i \left(p'(x_i + x_j) - c_i\right) = 0, \\ &p'(x_i + x_j) - c_i \leq 0, \\ &x_i \geq 0, \end{aligned}$$

are satisfied for $i = 1, 2$. The proposition follows immediately. □

**Proposition 3.2.** *Let the public good production function p be continuously differentiable and strictly concave. In any equilibrium of the game with uncertainty about costs,* ex post *total contributions and social welfare are never greater than if* $c_1$ *were common knowledge. They are strictly less with positive probability if* $\Pr(c_1 < c_2) > 0$*,* $\Pr(c_1 > c_2) > 0$*, and* $p'(0) > c_2$*.*

*Proof.* Let $\sigma$ be an equilibrium of the game with uncertainty about costs. I begin by proving that *ex post* total contributions are weakly less in equilibrium than if $c_1$ were common knowledge; i.e., that

$$s_1(c_1, \mu_1(c_1)) + s_2(\mu_1(c_1)) \leq \max\{x^*(c_1), x^*(c_2)\} \tag{A.2}$$

for all $c_1$. By Proposition 3.1, in equilibrium country 2 contributes the same amount $\tilde{x}_2 \geq 0$ in response to all messages on the path of play: $s_2(\mu_1(c_1)) = \tilde{x}_2$ for all $c_1 \in T_1$. The first-order conditions for an optimal choice by country 1 then give

$$s_1(c_1, \mu_1(c_1)) = \max\{x^*(c_1) - \tilde{x}_2, 0\}. \tag{A.3}$$

Since any contribution above a country's stand-alone contribution is strictly dominated, $\tilde{x}_2 \leq x^*(c_2)$. We thus have

$$s_1(c_1, \mu_1(c_1)) + s_2(\mu_1(c_1)) = \max\{x^*(c_1), \tilde{x}_2\} \leq \max\{x^*(c_1), x^*(c_2)\},$$

giving us the inequality (A.2).

Next, I prove that *ex post* contributions are strictly less than the complete-information benchmark for all $c_1 > c_2$ if $\Pr(c_1 < c_2) > 0$, $\Pr(c_1 > c_2) > 0$, and $p'(0) > c_2$. To this end, I will show that these conditions imply $\tilde{x}_2 < x^*(c_2)$. The assumption that $p'(0) > c_2$ implies $x^*(c_2) > 0$. As $\tilde{x}_2 \leq x^*(c_2)$, the best-response condition (A.3) gives $s_1(c_1, \mu_1(c_1)) > 0$ for all $c_1 < c_2$. Therefore, since $\Pr(c_1 < c_2) > 0$, the first-order condition for a best response by country 2 cannot be satisfied at $x_2 = x^*(c_2)$:

$$\int_{T_1} p'\left(s_1(c_1, \mu_1(c_1)) + x^*(c_2)\right) dF_1 - c_2 < \int_{T_1} p'\left(x^*(c_2)\right) dF_1 - c_2 = 0.$$

On the path of play, when $c_1 > c_2$ (which, by construction, occurs with positive probability), the total contribution is $\tilde{x}_2$ (by equation (A.3)), whereas it would be the strictly greater value $x^*(c_2)$ under complete information.

The final task is to prove that the lower total contribution under incomplete information implies lower *ex post* social welfare. Let $c_1$ be fixed and let $\ell$ denote the country with the lower marginal cost of effort,[12] so $c_\ell = \min\{c_1, c_2\}$. Define the *ex post* social welfare function as the sum of the countries' utilities,

$$U(x_1, x_2) = 2p(x_1 + x_2) - c_1 x_1 - c_2 x_2.$$

This is a strictly concave function that is maximized by a contribution scheme in which $\ell$ spends $x^*(c_\ell/2)$ and the other country spends nothing. Let $(x_1', x_2') = (s_1(c_1, \mu_1(c_1)), s_2(\mu_1(c_1)))$ denote the contribution scheme realized on the equilibrium path under incomplete information, and let $(x_1'', x_2'')$ be any equilibrium contribution scheme if $c_1$ were common knowledge. By Lemma A.1, social welfare under complete information is

$$U(x_1'', x_2'') = 2p(x^*(c_\ell)) - c_\ell x^*(c_\ell).$$

By equation (A.2), $x_1' + x_2' \leq x^*(c_\ell)$, strictly so for all $c_1 > c_2$ if $\Pr(c_1 < c_2) > 0$, $\Pr(c_1 > c_2) > 0$, and $p'(0) > c_2$. This inequality, combined with strict concavity

[12] If $c_1 = c_2$, $\ell$ may be either country.

of the social welfare function, gives

$$\begin{aligned} U(x_1', x_2') &= 2p(x_1' + x_2') - c_1 x_1' - c_2 x_2' \\ &\leq 2p(x_1' + x_2') - c_\ell(x_1' + x_2') \\ &\leq 2p(x^*(c_\ell)) - c_\ell x^*(c_\ell) \\ &= U(x_1'', x_2''), \end{aligned}$$

with the final inequality holding strictly if $x_1' + x_2' < x^*(c_\ell)$. *Ex post* social welfare therefore is weakly less under incomplete information, strictly so if the additional conditions of the proposition are met. □

### A.1.2 Intelligence Sharing

**Proposition 4.1.** *Consider an equilibrium of the intelligence sharing game, and let $\bar{x}_2$ denote the greatest amount country 2 spends on the equilibrium path. In any subgame on the equilibrium path in which country 2 spends $x_2 < \bar{x}_2$, country 1 spends nothing and believes there is zero probability the threshold lies in $(x_2, \bar{x}_2)$.*

*Proof.* Take any equilibrium of the intelligence sharing game, and let $\bar{x}_2 = \sup_{z \in Z} s_2(\mu_1(z))$. Consider a subgame in which country 1 has received the signal $z$ and sent the corresponding message $\mu_1(z)$, and suppose $s_2(\mu_1(z)) < \bar{x}_2$. If country 1 spends $s_1(z, \mu_1(z)) > 0$ in this subgame, then there is a profitable deviation available: country 1 could instead send a message $m_1$ such that $s_2(m_1) > s_2(\mu_1(z))$, reduce its own contribution by the difference, and attain the same probability of success at strictly less cost to itself. Therefore, $s_1(z, \mu_1(z)) = 0$, as claimed.

Next, suppose country 1's updated belief places positive mass on $(x_2, \bar{x}_2)$, so there is $x_2' \in (x_2, \bar{x}_2)$ such that $F_y(x_2' | z) > F_y(x_2 | z)$. Then it would be profitable for country 1 to deviate to a message $m_1$ such that $s_2(m_1) \geq x_2'$ and then spend nothing, yielding a greater probability of success at the same cost to itself. Therefore, country 1's updated belief must place zero probability on $(x_2, \bar{x}_2)$, as claimed. □

**Corollary 4.2.** *If the support of country 1's updated beliefs includes $[0, \frac{1}{c_2}]$ after every signal $z \in Z$, then there is no influential equilibrium.*

*Proof.* Suppose the support of $F_y(\cdot | z)$ includes $[0, \frac{1}{c_2}]$ for all $z \in Z$, and suppose there is an influential equilibrium. As in Proposition 4.1, let $\bar{x}_2 =$

$\sup_{z \in Z} s_2(\mu_1(z))$. We have $\bar{x}_2 \leq \frac{1}{c_2}$, as spending more than this is strictly dominated for country 2. By definition of an influential equilibrium, there is a subgame along the path of play following the signal $z$ in which $s_2(\mu_1(z)) < \bar{x}_2$. By Proposition 4.1, country 1's updated belief in this subgame must place zero probability on $(s_2(\mu_1(z)), \bar{x}_2)$, contradicting our assumption on the support of these beliefs. Therefore, there is no influential equilibrium. □

**Proposition 4.3.** *If the signal is perfectly informative, then there is a fully separating, influential equilibrium of the intelligence-sharing game.*

*Proof.* I begin by constructing the claimed equilibrium. Let the messaging strategy $\mu_1$ be fully separating, so $\mu_1(z) = z$ for all $z \in Z$. Let country 2's strategy be

$$s_2(m_1) = \begin{cases} m_1 & m_1 < \frac{1}{c_2}, \\ \frac{1}{c_2} & \frac{1}{c_2} \leq m_1 \leq \frac{1}{c_1} + \frac{1}{c_2}, \\ 0 & m_1 > \frac{1}{c_1} + \frac{1}{c_2}. \end{cases}$$

Along the path of play, let country 1's strategy be

$$s_1(z, z) = \begin{cases} 0 & z < \frac{1}{c_2}, \\ z - \frac{1}{c_2} & \frac{1}{c_2} \leq z \leq \frac{1}{c_1} + \frac{1}{c_2}, \\ 0 & z > \frac{1}{c_1} + \frac{1}{c_2}. \end{cases}$$

Off the path of play (i.e., in subgames in which $m_1 \neq z$), let $s_1(z, m_1)$ be any best response for country 1 to $s_2(m_1)$. Country 1's interim utility function,

$$u_1(x_1 \mid m_1, z) = \mathbf{1}\{x_1 + s_2(m_1) \geq z\} - c_1 x_1,$$

is a step function that is maximized at either 0 or $z - s_2(m_1)$, so a best response always exists. Finally, let country 2's updated beliefs $\lambda_2(m_1)$ be a degenerate distribution on $m_1$ for all $m_1 \in M_1$. I claim that the assessment $(\mu_1, s_1, s_2, \lambda_2)$ is an equilibrium.

I proceed by showing that the proposed contribution strategies are sequentially rational. Consider country 2's strategy. After receiving the message $m_1$, country 2's belief about the threshold $y$ is a point mass on $m_1$. Country 2's interim utility function is thus

$$u_2(x_2 \mid m_1) = \mathbf{1}\{s_1(m_1, m_1) + x_2 \geq m_1\} - c_2 x_2,$$

which is maximized at 0 or at $z - s_1(m_1, m_1)$. Specifically, 0 is a maximizer if country 1's contribution is sufficient for success ($s_1(m_1, m_1) \geq m_1$) or the remaining amount necessary to succeed exceeds country 2's willingness to contribute ($z - s_1(m_1, m_1) \geq \frac{1}{c_2}$). Conversely, if $0 \leq z - s_1(m_1, m_1) \leq \frac{1}{c_2}$, then $z - s_1(m_1, m_1)$ is a maximizer. It is then immediate from the definitions of $s_1(z, z)$ and $s_2$ that country 2's contribution strategy is optimal, given its beliefs. It is analogous to confirm that country 1's contribution strategy along the path of play ($m_1 = z$) is optimal, given country 2's strategy. In cases off the path of play ($m_1 \neq z$), country 1's contribution is optimal by construction.

The next step is to show that country 1's messaging strategy is incentive compatible—i.e., that country 1 never has an incentive to falsely report the signal it has received. If $z \leq \frac{1}{c_2}$, then country 1's proposed messaging strategy yields its first-best outcome (guaranteed success at no cost to itself), so no profitable deviation is available. If $\frac{1}{c_2} < z \leq \frac{1}{c_1} + \frac{1}{c_2}$, then deviating to any message other than $z$ would cause country 2 to contribute weakly less, so no such deviation may be profitable. Lastly, if $z > \frac{1}{c_1} + \frac{1}{c_2}$, then the most country 1 could induce country 2 to contribute by deviating to a different message is $x_2 = \frac{1}{c_2}$. Even in that case, country 1's best response is to contribute 0, assuring failure of the joint venture and a payoff of 0, the same as under the proposed messaging strategy. Therefore, there is no profitable deviation available.

The final step is to show that country 2's beliefs are consistent with the application of Bayes' rule, which is immediate from the definition of $\lambda_2$. □

### A.1.3 Uncertainty about Comparative Advantage

Before proving the proposition on the existence of a division of labor equilibrium, I state a lemma about when the proposed strategies constitute Nash equilibria of the contribution subgame.

**Lemma A.2.** *In the contribution stage of the two-method game, suppose $\beta_1$ is common knowledge. The strategy profile $\{(x_1^A, x_1^B), (x_2^A, x_2^B)\} = \{(1,0), (0,1)\}$ is a Nash equilibrium if and only if the following conditions are met:*

$$p(1,1) - p(0,1) \geq \alpha_1, \tag{A.4}$$

$$p(1,1) - p(1,0) \geq \beta_2. \tag{A.5}$$

*The strategy profile* $\{(x_1^A, x_1^B), (x_2^A, x_2^B)\} = \{(0,1), (1,0)\}$ *is a Nash equilibrium if and only if:*

$$p(1,1) - p(0,1) \geq \alpha_2, \tag{A.6}$$

$$p(1,1) - p(1,0) \geq \beta_1. \tag{A.7}$$

*Proof.* I will prove the first statement; the proof of the second is analogous. Under the given strategy profile, since $x_2^B = 1$, it cannot be profitable for country 1 to deviate to any strategy with $x_1^B = 1$. Therefore, the only deviation we must consider for country 1 is $(x_1^A, x_1^B) = (0,0)$. This deviation is unprofitable if and only if the condition (A.4) holds. Similarly, because $x_1^A = 1$ under the given strategy profile, the only deviation we must consider for country 2 is $(x_2^A, x_2^B) = (0,0)$. This is unprofitable if and only if the condition (A.5) holds. □

**Proposition 5.1.** *In the two-method game, there exists a division of labor equilibrium if the following inequalities are satisfied:*

$$p(1,1) - p(0,1) \geq \max\left\{\alpha_1, \alpha_2, \beta_1^L\right\}, \tag{5.2}$$

$$p(1,1) - p(1,0) \geq \max\left\{\alpha_1, \beta_1^L, \beta_2\right\}. \tag{5.3}$$

*Proof.* I begin by constructing the claimed equilibrium. Let the messaging strategy $\mu_1$ be fully separating, so $\mu_1(\beta_1) = \beta_1$ for all $\beta_1 \in T_1$. Let country 2's strategy be

$$s_2(m_1) = \begin{cases} (1,0) & m_1 = \beta_1^L, \\ (0,1) & m_1 = \beta_1^H. \end{cases}$$

Along the path of play, let country 1's strategy be

$$s_1(\beta_1, \beta_1) = \begin{cases} (0,1) & \beta_1 = \beta_1^L, \\ (1,0) & \beta_1 = \beta_1^H. \end{cases}$$

Off the path of play (i.e., in subgames in which $m_1 \neq \beta_1$), let country 1's strategy be any best response to $s_2(m_1)$; as the game is finite, a best response exists. Finally, let country 2's updated beliefs after each $m_1$ place probability 1 on $\beta_1 = m_1$.

I proceed by showing that the proposed contribution strategies are sequentially rational. The conditions (5.2) and (5.3) imply that equations (A.4)– (A.7) are satisfied. Therefore, by Lemma A.2, country 2's proposed actions are best responses given its beliefs, as are country 1's proposed actions in the subgames on the equilibrium path. In the subgames off the equilibrium path, country 1's actions are best responses by construction.

Next, I show that country 1's messaging strategy is incentive compatible: neither type of country 1 can strictly improve its payoff by deviating from its messaging strategy. Consider the maximal payoff to the $B$-advantaged type after falsely reporting $\beta_1^H$. Since country 2 contributes $x_2^B = 1$ after receiving the $A$-advantaged message, we only need to consider actions with $x_1^B = 0$. The condition for the deviation to be unprofitable is thus

$$p(1,1) - \beta_1^L \geq \max\left\{p(0,1), p(1,1) - \alpha_1\right\},$$

which follows from equation (5.2) and $\beta_1^L < \alpha_1$. Similarly, the condition for it to be unprofitable for the $A$-advantaged type to deviate in the messaging stage is

$$p(1,1) - \alpha_1 \geq \max\left\{p(1,0), p(1,1) - \beta_1^H\right\},$$

which follows from equation (5.3) and $\beta_1^H > \alpha_1$.

The final step is to confirm that country 2's updated beliefs are consistent with Bayes' rule wherever possible, which is true by construction. □

## A.2 Two-Sided Uncertainty about Willingness to Contribute

We saw in Section 3 that there cannot be any influential communication about a state's willingness to contribute to a joint project. To show that this result is not an artifact of the one-sided informational setup, I extend it to an environment in which both countries have private information. The lack of influential communication persists, albeit under more restrictive conditions on the distribution of types and the public good production function.

To model two-sided uncertainty about costs, let each country's marginal cost of effort, $c_i$, be drawn according to the cumulative distribution function $F_i$. I assume that each $F_i$ is continuous, has support on the interval $T_i = [\underline{c}_i, \bar{c}_i]$, and is common knowledge. I also assume that the two types are drawn independently of one another.

In the messaging stage, each country simultaneously sends a message $m_i \in M_i$ according to the messaging strategy $\mu_i : T_i \to M_i$. Once again, for convenience let $M_i = T_i$. Each country $i$, after receiving its partner's message $m_j$, updates its belief about the partner's type $c_j$ to the probability measure $\lambda_i(m_j)$. Let $\Gamma(m_i, m_j)$ denote the contribution subgame that ensues after country $i$

sends $m_i$ and country $j$ sends $m_j$. A country's contribution strategy is a function $s_i : T_i \times M_i \times M_j$, so $s_i(c_i, m_i, m_j)$ denotes the contribution of type $c_i$ of country $i$ in the subgame $\Gamma(m_i, m_j)$.

The definition of an influential equilibrium is similar to the one-sided case, though we must now be careful not to include equilibria that are "influential" with zero probability. An influential equilibrium is one with the following characteristics:

1. There is a country $i$ that sends distinct messages depending on its type: $\mu_i(c_i) \neq \mu_i(c_i')$ for some $c_i, c_i' \in T_i$.
2. With positive probability, that country's choice of message affects its partner's contribution: there is a set of types $\tilde{T}_j \subseteq T_j$, with $\Pr(c_j \in \tilde{T}_j) > 0$, such that $s_j(c_j, \mu_j(c_j), \mu_i(c_i)) \neq s_j(c_j, \mu_j(c_j), \mu_i(c_i'))$ for all $c_j \in \tilde{T}_j$.

In the one-sided case, influential communication is impossible because the informed country prefers to say whatever makes its partner give as much as possible. Similarly, in the two-sided case there cannot be an equilibrium where all types of a country's partner contribute more after receiving one message than another. Given the incentive to free-ride, no type of a country will prefer to send a message that guarantees a lower contribution by its partner. The following proposition formalizes this point.

**Proposition A.3.** *There is no equilibrium that satisfies all of the following criteria:*

1. *There is a pair of messages $m_i, m_i' \in M_i$, with $m_i \neq m_i'$, such that $m_i = \mu_i(c_i)$ for some $c_i \in T_i$ and $m_i' = \mu_i(c_i')$ for some $c_i' \in T_i$.*
2. *For almost all $c_j \in T_j$, $s_j(c_j, \mu_j(c_j), m_i') \geq s_j(c_j, \mu_j(c_j), m_i)$.*
3. *There is a set of types $\tilde{T}_j \subseteq T_j$ such that $\Pr(c_j \in \tilde{T}_j) > 0$ and $s_j(c_j, \mu_j(c_j), m_i') > s_j(c_j, \mu_j(c_j), m_i)$ for all $c_j \in \tilde{T}_j$.*

*Proof.* Take any assessment that meets the conditions of the proposition. Consider a deviation whereby type $c_i$ of country $i$ sends the message $m_i'$ and then, after receiving country $j$'s message, makes the same contribution as if it had sent the prescribed message $m_i$. For ease of exposition, let $s_{i|c_i}(c_j) = s_i(c_i, \mu_i(c_i), \mu_j(c_j))$ denote the contribution of type $c_i$ that is realized when its partner sends the message prescribed for type $c_j$, and define $s_{j|c_j}$ analogously. By construction, $s_{j|c_j}(c_i') \geq s_{j|c_j}(c_i)$ for almost all $c_j \in T_j$, and strictly so on

$\tilde{T}_j$. As $p$ is strictly increasing, the difference in expected utility between the deviation and type $c_i$'s proposed strategy is

$$\begin{aligned}
&\int_{T_j} \left[ p\left(s_{i\,|\,c_i}(c_j) + s_{j\,|\,c_j}(c_i')\right) - p\left(s_{i\,|\,c_i}(c_j) + s_{j\,|\,c_j}(c_i)\right)\right] dF_j \\
&\qquad \geq \int_{\tilde{T}_j} \left[ p\left(s_{i\,|\,c_i}(c_j) + s_{j\,|\,c_j}(c_i')\right) - p\left(s_{i\,|\,c_i}(c_j) + s_{j\,|\,c_j}(c_i)\right)\right] dF_j \\
&\qquad > 0.
\end{aligned}$$

Therefore, the assessment is not an equilibrium. □

I first examine the possibility of a fully separating equilibrium, in which each country always reveals its exact cost of effort. All we need to rule this out is strict concavity of the public good production function.

**Proposition A.4.** *If $p$ is continuously differentiable and strictly concave, then there is no fully separating influential equilibrium in the game with two-sided uncertainty about costs.*

*Proof.* Let $p$ be continuously differentiable and strictly concave, and consider an equilibrium in which $\mu_i(c_i) = c_i$ for all $c_i$. By Lemma A.1, each type's contribution on the path of play is given by

$$s_i(c_i, c_i, c_j) = \begin{cases} x^*(c_i) & c_i < c_j, \\ x^*(c_i) - s_j(c_j, c_j, c_i) & c_i = c_j, \\ 0 & c_i > c_j, \end{cases}$$

where the stand-alone contribution function $x^*$ is defined as in (A.1). This expression is weakly decreasing in $c_j$. Therefore, if the assessment is influential, it meets the conditions of Proposition A.3, contradicting the assumption of equilibrium. □

To rule out noisier types of influential communication, where countries only partially reveal their types, some additional structure on the model is necessary. First, I restrict attention to *interval messaging strategies*, in which each message corresponds to an interval of types. Given a messaging strategy $\mu_i$, let $\mathscr{C}_i(m_i)$ denote the set of types of country $i$ that send $m_i$. Formally, $\mu_i$ is an interval messaging strategy if every $\mathscr{C}_i(m_i)$ is convex. Second, to ease the characterization of best responses, I assume the function $p$ is quadratic. The quadratic functional form is convenient because it implies that a country's optimal contribution depends only on the expected value of its partner's contribution. Barbieri and Malueg (2013) discuss the convenience and importance of this kind of best-response linearity in modeling public goods problems. I first state a helpful lemma, then the main proof.

**Lemma A.5.** *Let $p$ be quadratic on $[0, \frac{1}{\underline{c}_1} + \frac{1}{\underline{c}_2}]$, and consider the contribution subgame $\Gamma(m_1, m_2)$ with beliefs $\lambda_1(m_2)$ and $\lambda_2(m_1)$. In any equilibrium of this subgame, contribution strategies are given by*

$$s_1(c_1, m_1, m_2) = \max\left\{0, x^*(c_1) - E_{\lambda_1(m_2)}[\max\{0, x^*(c_2) - \bar{x}_1\}]\right\}, \tag{A.8}$$

$$s_2(c_2, m_2, m_1) = \max\{0, x^*(c_2) - \bar{x}_1\}, \tag{A.9}$$

*where $\bar{x}_1$ solves*

$$h(x) = x - E_{\lambda_2(m_1)}\left[\max\left\{0, x^*(c_1) - E_{\lambda_1(m_2)}[\max\{0, x^*(c_2) - x\}]\right\}\right] = 0. \tag{A.10}$$

*Proof.* I begin by characterizing the best response functions. The quadraticity assumption implies $p'$ is linear on $[0, \frac{1}{\underline{c}_1} + \frac{1}{\underline{c}_2}]$. Contributions $x_i > \frac{1}{\underline{c}_i}$ are strictly dominated for all types of country $i$, so we can restrict each country's action set to $[0, \frac{1}{\underline{c}_i}]$ without loss of generality. The first-order condition for $x_i \in (0, x^*(c_i)]$ to be a best response for type $c_i$ is thus

$$\begin{aligned} 0 &= E_{\lambda_i(m_j)}\left[p'\left(x_i + s_j(c_j, m_j, m_i)\right) - c_i\right] \\ &= p'\left(x_i + E_{\lambda_i(m_j)}[s_j(c_j, m_j, m_i)]\right) - c_i, \end{aligned}$$

which is equivalent to $x_i = x^*(c_i) - E_{\lambda_i(m_j)}[s_j(c_j, m_j, m_i)]$. The function $p$ is concave on the set of feasible contribution profiles, so the first-order conditions are sufficient for a best response, giving us

$$s_i(c_i, m_i, m_j) = \max\left\{0, x^*(c_i) - E_{\lambda_i(m_j)}[s_j(c_j, m_j, m_i)]\right\} \tag{A.11}$$

for each $c_i \in T_i$ and each $i = 1, 2$.

Now take an equilibrium of the subgame, and let $\bar{x}_1 = E_{\lambda_2(m_1)}[s_1(c_1, m_1, m_2)]$ denote the expected value of country 1's contribution. It is immediate from (A.11) that

$$s_2(c_2, m_2, m_1) = \max\{0, x^*(c_2) - \bar{x}_1\}$$

for each $c_2 \in T_2$, as in (A.9). It then follows, again from (A.11), that

$$s_1(c_1, m_1, m_2) = \max\left\{0, x^*(c_1) - E_{\lambda_1(m_2)}[\max\{0, x^*(c_2) - \bar{x}_1\}]\right\}$$

for each $c_1 \in T_1$, as in (A.8). Substituting this into the definition of $\bar{x}_1$ gives

$$\bar{x}_1 = E_{\lambda_2(m_1)}\left[\max\left\{0, x^*(c_1) - E_{\lambda_1(m_2)}[\max\{0, x^*(c_2) - \bar{x}_1\}]\right\}\right],$$

which is equivalent to $h(\bar{x}_1) = 0$. □

**Proposition A.6.** *If $p$ is quadratic on $[0, \frac{1}{\underline{c}_1} + \frac{1}{\underline{c}_2}]$, there is no influential equilibrium in interval messaging strategies in the game with two-sided uncertainty about costs.*

*Proof.* Take any equilibrium in which both countries employ interval messaging strategies, and at least one country's message at least partially reveals its type. Without loss of generality, I will assume this is country 1, so there are messages $m_1$ and $m_1'$ in the range of $\mu_1$ such that $m_1 \neq m_1'$. Furthermore, let $m_1'$ be the message sent by higher-cost types, so $\sup \mathscr{C}_1(m_1) \leq \inf \mathscr{C}_1(m_1')$.

I claim that country 2 never contributes more after receiving $m_1$ than after $m_1'$. For any message $m_2$, let $\bar{x}_1$ denote the expected contribution by country 1 in the subgame $\Gamma(m_1, m_2)$, and let $\bar{x}_1'$ denote the same for $\Gamma(m_1', m_2)$. Since country 2's contribution is weakly decreasing in its expectation of country 1's, per (A.9), it will suffice to show that $\bar{x}_1 \geq \bar{x}_1'$. This is immediate if $\bar{x}_1' = 0$, so suppose $\bar{x}_1' > 0$. This means some type of country 1 that sends $m_1'$ contributes a positive amount when it expects country 2 to best-respond to $\bar{x}_1'$, which in turn means every type that sends $m_1$ would do so. Since every type that sends $m_1$ has a greater stand-alone contribution than any that sends $m_1'$, this implies

$$\begin{aligned}
&\bar{x}_1' - E_{\lambda_2(m_1)}\left[\max\left\{0, x^*(c_1) - E_{\lambda_1(m_2)}\left[\max\left\{0, x^*(c_2) - \bar{x}_1'\right\}\right]\right\}\right] \\
&\quad < \bar{x}_1' - E_{\lambda_2(m_1')}\left[\max\left\{0, x^*(c_1) - E_{\lambda_1(m_2)}\left[\max\left\{0, x^*(c_2) - \bar{x}_1'\right\}\right]\right\}\right] \\
&\quad = 0,
\end{aligned}$$

where the equality follows from (A.10). Combining this with

$$\bar{x}_1 - E_{\lambda_2(m_1)}\left[\max\left\{0, x^*(c_1) - E_{\lambda_1(m_2)}[\max\{0, x^*(c_2) - \bar{x}_1\}]\right\}\right] = 0,$$

also from (A.10), gives $\bar{x}_1 > \bar{x}_1'$, as the above expression is non-decreasing in $\bar{x}_1$. Therefore, no type of country 2 ever gives more after receiving $m_1$ than after $m_1'$: $s_2(c_2, m_2, m_1) \leq s_2(c_2, m_2, m_1')$ for all $c_2 \in T_2$ and $m_2 \in M_2$. The equilibrium thus must not be influential, or else it would contradict Proposition A.3. □

Although this proposition only covers the quadratic case, I suspect that the basic logic—that every type of a country gives less after receiving a "willing" signal than an "unwilling" one—would also hold under broader conditions.

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