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Governing climate geoengineering: Side-payments are not enough

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Abstract

Climate geoengineering strategies can help reduce the economic and ecological impacts of global warming. However, governing geoengineering is challenging: since climate preferences vary across countries, excessive deployment relative to the socially optimal level is likely. Through a laboratory experiment on a public good-or-bad game, we study whether side-payments can address this governance problem. While theoretically effective, our experimental results show only a modest impact of side-payments on outcomes, especially in a multilateral setup. Replacing unstructured bilateral exchanges with a treaty framework simplifies the action space and performs moderately better.

JEL Codes: C70, C90, H40, Q50

Keywords: climate governance, public good-or-bad, free-driving, transfers, promises, experiment, Coase theorem

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1 Introduction

Geoengineering offers a possible way to cope with the climate emergency. Its implementation at a planetary-level remains uncharted territory for scientists and policy-makers. Most governments of the world have signed the Paris agreement, whose long-term goal is to stabilize the Earth's temperature between 1.5 and 2 °C. Policies to reduce greenhouse gases are discussed or legislated in many countries. However, the inertia in the climate and socio-economic responses is such that additional strategies might be needed to manage global warming and mitigate its short-term climate consequences. Carbon sequestration techniques would need to be considerably scaled-up. Another geoengineering option, which has been researched and discussed for a while, is directly intervening on the Earth's temperature. Reducing incoming solar radiation allows to rapidly cool the planet's temperature, and thus limit climate impacts. This result can be achieved by injecting reflecting aerosol particles into the stratosphere, mimicking the well-studied consequences of volcanic eruptions. Solar radiation management (SRM) interventions have been shown to be climatically effective (Kravitz et al., 2020; Irvine et al., 2019), and economically appealing (Barrett, 2008). This paper is about the strategic impacts of SRM, which are largely unknown, as the world has no experience with it. We shed light on the issue through laboratory experiments.

There are reasons to believe that climate geoengineering will raise major governance challenges (Schelling, 1996; Victor et al., 2009; Rickels et al., 2020; Sugiyama et al., 2018; Horton et al., 2018) and substantially alter the strategic incentives of nations. Weitzman (2015) has introduced a model of SRM strategic investments where nations with diverse ideal temperatures can unilaterally deploy solar geoengineering to cool the planet. Diversity in ideal temperatures is rooted in the different geographical locations of nations, which implies differences in average temperatures. This novel setting — called *public good-or-bad* — in equilibrium results in an excessive deployment of solar geoengineering. Given the low marginal deployment cost, the country with the highest preference for climate geoengineering deploys it to a level that can hurt most other countries and deteriorate global social welfare. This over-provision of climate geoengineering is called *free-driving*, in contrast to the well-known free-riding phenomenon for canonical public goods, which is illustrated by the underprovision of climate mitigation through emission abatement. In a seminal experimental study, Abatayo et al. (2020) provide empirical evidence of free-driving and its welfare-deteriorating consequences. Here we focus on what can be done to correct free-driving and channel climate geoengineering toward improving global social welfare — the geoengineering governance.

To curb free-driving, Weitzman (2015) proposes a top-down approach involving a binding international treaty established through voting. Instead, this paper takes a bottom-up approach to tackle governance problems. We allow individual nations to offer side-payments to others, conditional on them following a requested geoengineering effort. This type of solution builds on the Coasian bargaining approach to externalities, which has experimentally been shown to obtain the optimal outcome most of the time (Hoffman and Spitzer, 1982, 1985). If a nation cools the planet excessively to reach its ideal temperature, it can inflict considerable damages on others. Other nations may hence be willing to offer sufficient compensation to the one deploying geoengineering to induce it to limit the cooling. We carry out a laboratory experiment to study the empirical capability of side-payments to restore efficiency. The experiment comprises two benchmark scenarios without side-payments ('Baseline' treatment) and four different scenarios with side-payments. We manipulate the complexity of the side-payment scheme and the number of decision-makers. Side-payments could take the form of a series of bilateral agreements that any party can make across a wide range of possible transfers and geoengineering targets ('Decentralized' treatment). Side-payments could instead happen in a centralized setting where side-payments from all those who stand to benefit from less geoengineering are pooled and distributed equally to all decision-makers who restrain geoengineering deployment ('Treaty' treatment). When there are only two decision-makers ($N = 2$), Treaty essentially restricts the strategy space about side-payments relative to Decentralized. In a multilateral setting ($N = 6$), Treaty may also facilitate coordination among decision-makers.[1]

This study brings original contributions to the growing stream of experimental studies about climate change. The extant literature considers especially the mitigation problem. Experiments often involve a modified versions of the voluntary contribution to a public goods game and have focused, for instance, the role of tipping points (Tavoni et al., 2011; Barrett and Dannenberg, 2017), uncertainty of impacts (Barrett and Dannenberg, 2012; Ghidoni et al., 2017), dynamic externalities (Calzolari et al., 2018; Sherstyuk et al., 2016), or commitment devices (Dengler et al., 2018).[2] Much less work concerns climate geoengineering. Abatayo et al. (2020) model the situation as a public good-or-bad game, which alters in fundamental ways the

[1]Geoengineering effort and deployment are used interchangeably.

[2]Another strand of the experimental literature investigates the efficacy of emission trading schemes (e.g., Cason, 1995; Jakob et al., 2017).

strategic environment of a public good game: (1) decision-makers differ in their goals about the aggregate outcome (i.e., in their ideal points in terms of global geoengineering), (2) the provision cost is low, in particular, it is lower than the potential benefit of climate geoengineering, and (3) decision-makers are characterized by single-peaked preferences over the aggregate outcome, leading to penalties both in case of over- and under-provision. The game refers to a scenario where the stock of greenhouse gas in the atmosphere has reached dangerous levels, and imminent climate damages can only be avoided by geoengineering climate.

The results of our experiment show that side-payments have limited effectiveness, especially in a multilateral setting. Although side-payments could in principle allow decision-makers to deploy solar geoengineering in a socially optimal way, both in Decentralized and Treaty, side-payments improve efficiency only by a modest amount. A careful analysis of the data provides possible reasons for this failure. We rule out any major role for confusion, social preferences, or low stakes. We document that participants continuously tried to move away from the free-driving outcome through a flurry of side-payments' promises. However, many of them were inadequate, as they were not in the mutual interest of both sender and recipient. Furthermore, some adequate promises were not fulfilled. As a result, too few side-payments took place. For instance, we report for Treaty a frequency of side-payments of 48% in economies of two and only of 28% in economies of six. Higher total surpluses tend to be associated with a higher number of side-payments. Studying these patterns, especially in relation to the Decentralized treatment, could help design more effective institutions.

The remainder of the paper is organized as follows: Section 2 provides a description of the experiment, including the illustration of the public good-or-bad game and its treatments, as well as details on the experimental procedures; Section 3 presents the theoretical benchmarks; Section 4 presents the main experimental results and the underlying the mechanisms; Section 5 concludes.

2 The experiment

2.1 Public good-or-bad game

The theoretical model for geoengineering decisions follows the public good-or-bad (GoB) game by Weitzman (2015), which considers an economy of $N \geq 2$ decision-makers who independently choose their geoengineering efforts. The interaction lasts for a finite number of periods, T. At the beginning of every period, each decision-maker i receives an endowment E, which can be used to provide a geoengineering effort, g_i, bounded below by zero and above by $\overline{g}$.[3] The cost of one unit of effort is $\alpha > 0$. Decision-makers choose about g_i simultaneously and observe all effort decisions in the economy at the end of each period. Efforts in the economy sum up to generate the global level of geoengineering, $G = \sum_{i=1}^{N} g_i$. Decision-makers are heterogeneous in their ideal level of global geoengineering, G_i^* (henceforth, ideal point). Furthermore, their preferences over global geoengineering are single-peaked: decision-maker i incurs losses when G is either above or below G_i^*. For simplicity, we assume that i will suffer the same amount of loss if G undershoots or overshoots G_i^* by the same number of units. The marginal loss from deviations from G_i^* is larger than the marginal cost of geoengineering, $\lambda > \alpha$. Hence, decision-maker i's payoff is:

$$\pi_i = E - \alpha g_i - \lambda |G - G_i^*| \, . \tag{1}$$

In the experiment, $E = 150$, $\alpha = 4$, $\lambda = 10$, and the effort is an integer number with $\overline{g} = 15$. All parameters are public information.

This characterization of geoengineering entails four simplifying assumptions that make the experiment tractable. First, the GoB game assumes that the only climate strategy available is geoengineering (it leaves out other climate strategies such as mitigation and adaptation).[4] Second, the GoB game assumes that geoengineering outcomes are fully deterministic and, as such, it abstracts from indirectly associated risks as, for instance, effects on ozone levels or rainfall patterns. Third, the GoB game assumes a repeated but *static* interaction. That is, geoengineering efforts in a given period do not affect the temperature in subsequent periods. Fourth, the GoB game assumes decision-makers to only differ in their ideal levels G_i^*, while they have identical initial endowment, action space, effort cost, and loss from deviations from G_i^*.

2.2 Treatments

The experiment comprises three treatments — Baseline, Decentralized, and Treaty — that differ in the possibility of enacting side-payments and the way to negotiate them. We will present the session structure, the stage game, and the implementation procedures. In all treatments, sessions included conditions with bilateral interactions and with multilateral interactions. In

[3]For simplicity, we rule out counter-geoengineering strategies, i.e., the possibility to undo other decision-makers' efforts (see Heyen et al., 2019; Abatayo et al., 2020, for discussions on the effects of counter-geoengineering).

[4]While both mitigation and adaptation require the accumulated effect of investments over several years, geoengineering is a short-term strategy. Therefore, we believe that keeping this particular climate strategy separated makes sense.

the first 10 periods, decision-makers repeatedly interacted in fixed pairs, $N = 2$ (economies of two, Parts 1 and 2). Decision-makers were randomly assigned an ideal point, which remained fixed throughout the session. Within each economy, there was a conflict because ideal points were never the same. In the following 15 periods, we pooled together three economies of two to form an economy of six (Part 3). The same decision-makers repeatedly interacted in a fixed matching with $N = 6$. Comparisons of bilateral versus multilateral interactions allow us to evaluate the relevance of this complexity on geoengineering and side-payment outcomes.

Baseline. This treatment served as a benchmark. The stage game was the GoB game, where decision makers simultaneously chose an effort $g_i = 0, 1, \ldots, 15$ (Section 2.1). In each session, four decision-makers received a low ideal point of 2 units (L_1, L_2, L_3, and L_4), four received a medium ideal point of 6 units (M_1, M_2, M_3, and M_4), and four received a high ideal point of 10 units (H_1, H_2, H_3, and H_4). In each session, we adopted a matching procedure to generate six independent economies of two and two independent economies of six, as follows. Economies of two combined (L_1, M_1), (L_2, H_2), (M_2, H_1), (L_3, M_3), (L_4, H_4), and (M_4, H_3), respectively. Economies of six combined $(L_1, L_2, M_1, M_2, H_1, H_2)$ and $(L_3, L_4, M_3, M_4, H_3, H_4)$, respectively, which ensured the same presence of low, medium, and high ideal points within every economy of six.[5]

Decentralized. Before choosing the geoengineering effort g_i, every decision-maker could make one conditional payment promise to somebody else, for an amount $T_{i,j}$ between 1 and 150. The payoff function for decision-maker i is:

$$\pi_i = E - \alpha g_i - \lambda |G - G_i^*| - I \times T_{i,j} + J \times \sum_{j \neq i} T_{j,i} \,, \tag{2}$$

where $I = 1$ if the decision-maker made a promise that the other fulfilled and $I = 0$ otherwise, and $J = 1$ if the decision-maker received a promise is received and fulfilled it and $I = 0$ otherwise. The promise is binding as the side-payment automatically occurs if the other decision-maker satisfies the request in terms of geoengineering effort. Requests must specify an effort lower, greater, or equal to an arbitrary level between 0 and 15.[6] Each period has two

[5] This matching protocol allows decision-makers who have interacted with each other in the economies of two to interact with each other again in the economies of six.

[6] "I will transfer XXX tokens if you produce an amount lower than/greater than/equal to YYY units".

stages. First, decision-makers simultaneously commit (or not) to a side-payment, and then all these promises are on public display for others in the economy to see before decisions are made in the second stage, with the same GoB game as in Baseline.

Treaty. Side-payments are possible through a two-stage decisional structure within a framework that mimics an international institution aimed at facilitating negotiations and coordination of decision-makers. Compared to the Decentralized treatment, Treaty exhibits three differences. First, the promise space is simplified. The amount of the payments can be either 34 or 70 tokens, and the request to others can specify a geoengineering effort equal to either 2 or 6 units. Second, not everyone can make promises. The decision-makers with the highest ideal point in the economy can only receive payments but not make promises to others. Hence, there can be a maximum of one promise in an economy of two and of four promises in an economy of six. Thus, the payoff function for those who can make promises is

$$\pi_i = E - \alpha g_i - \lambda |G - G_i^*| - I \times T_{i,j} \ , \tag{3}$$

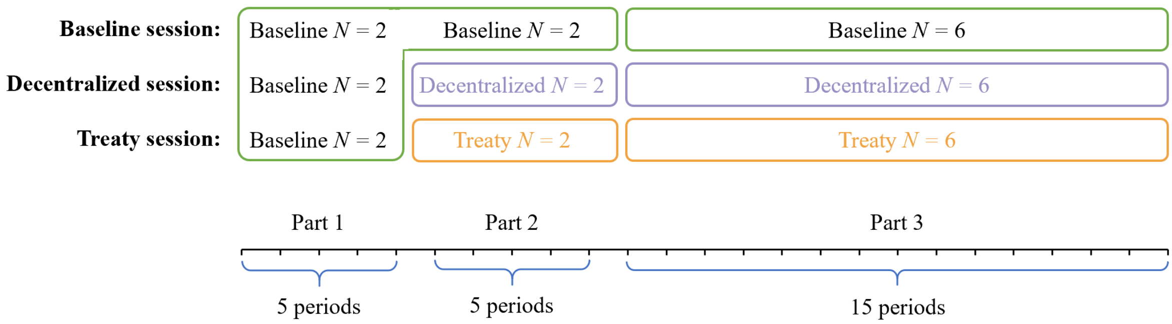
while the payoff for those who cannot make promises is

$$\pi_i = E - \alpha g_i - \lambda |G - G_i^*| + J \times \sum_{j \neq i} T_{j,i} \ . \tag{4}$$

Third, in economies of six, side-payments embeds multilateral elements. For once, side-payments are paid out only if both decision-makers with the highest ideal point fulfill the request and do so by equally splitting the geoengineering effort ($1+1$, or $3+3$). Moreover, when the request is fulfilled, the amounts promised by all decision-makers are pooled together and then equally distributed to the two decision-makers with the highest ideal point. The same outcome could be reached in the Decentralized treatment but would require a considerable degree of coordination.

In both Decentralized and Treaty, participants faced the same rules as in Baseline for Part 1 (i.e., the first five periods), while rules were treatment-specific in Parts 2 and 3 (Figure 1). The reasons were for participants to familiarize themselves with the simplest version of the GoB game and establish a common performance measure to assess the treatment effects.

Figure 1: Experimental sessions



Notes: No. participants (no. sessions) were 72 (3) in Baseline, 72 (3) in Decentralized, and 120 (5) in Treaty. Session dates: 21/05/2018, 23/05/2018, 24/05/2018, 11/06/2018, 18/06/2018, 20/06/2018, and 20/06/2018. Data from the Baseline sessions have already been used by Abatayo et al. (2020).

2.3 Experimental procedures

A team of two persons constituted the basic decision-making unit in all treatments. Participants within a pair could chat with each other for up to one or two minutes and had to reach a unanimous decision (between-teams communication was not possible). The team composition was random and kept constant for the duration of the session. Teams are generally considered more rational than individuals making decisions in isolation (see, for example, Charness and Sutter, 2012). One motivation for this design choice was to minimally capture the collective processes behind national choices generated by countries.

Communication was not allowed, except via chat with one own teammate. The experiment was neutrally framed: we never mentioned climate change, decision-makers were referred to as "teams", economies were referred to as "groups", and "geoengineering" was referred to as production. The experimenter read the instructions aloud while participants followed their own printed copy (see Appendix, Section B.1). Participants completed a quiz on the instructions (see Appendix, Section B.2) and were asked to write on paper the results for each round to ensure they paid attention. No eye contact was possible among participants. Before leaving the lab, participants completed a questionnaire (see Appendix, Section B.3). Participants could rely on a calculator to simulate their hypothetical earnings by entering their hypothetical effort and that of others.[7]

A total of 264 students participated in the experiment, divided into sessions of exactly 24 participants; they were recruited via ORSEE (Greiner, 2015). Sessions were conducted at the

[7]In Treaty, participants could also simulate the payoff impact of paying or receiving side-payments.

Table 1: Theoretical benchmarks

		Economies of two ($N = 2$)			Economy of six ($N = 6$)	
		Economy (L, M)	Economy (L, H)	Economy (M, H)	Economy (L, L, M, M, H, H)	
Social optimum		$G = 2$	$G = 2$	$G = 6$	$G = 6$	
SPNE Baseline		$g_L = 0, g_M = 6$	$g_L = 0, g_H = 10$	$g_M = 0, g_H = 10$	$g_{H1} + g_{H2} = 10$	
SPNE Decentralized	Efforts	$g_L = 0, g_M = 2$	$g_L = 0, g_H = 2$	$g_L = 0, g_H = 6$	$g_{H1} + g_{H2} = 10$	$g_{H1} + g_{H2} = 6$
	Transfers	$T_L = -[24, 40]$	$T_L = -[48, 80]$	$T_M = -[24, 40]$	None	$T_{L1} + T_{L2} +$ $T_{M1} + T_{M2} = -[64, 80]$
SPNE Treaty	Efforts	$g_L = 0, g_M = 2$	$g_L = 0, g_H = 2$	$g_L = 0, g_H = 6$	$g_{H1} + g_{H2} = 10$	$g_{H1} + g_{H2} = 6$
	Transfers	$T_L = -34$	$T_L = -70$	$T_M = -34$	None	$T_{L1} + T_{L2} +$ $T_{M1} + T_{M2} = -68$
Gini index (SO)		0.10	0.21	0.14	0.05	0.05
Gini index (SPNE)		0.04	0.12	0.01	0.13	0.04

Notes: For $N = 6$ we only report non-zero efforts, i.e. $g_i > 0$; omitted efforts are hence equal to 0. Gini index for $N = 2$ is computed using cumulative equilibrium in Baseline earnings over 5 periods, while Gini index for $N = 6$ is computed using cumulative equilibrium earnings over 15 periods; for SO, we assume that the two M teams exert effort of 3 each, for the SPNE we assume the two M teams to pay 34 each to the two H teams.

BLESS laboratory of the University of Bologna.[8] On average, participants earned 21 EUR.[9] The experiment was programmed with zTree (Fischbacher, 2007).

3 Theoretical benchmarks

To evaluate the empirical results, we present the theoretical benchmarks of the socially optimum and the subgame perfect Nash equilibrium (SPNE). Our measure of social optimality is the total surplus, i.e., the sum of all decision-makers' payoffs in the economy in a period.[10] Table 1 provides an overview for economies of two and economies of six.

3.1 Economies of two

We present the social optimum and SPNE benchmarks for economies of two.

[8]We conducted two additional sessions of Treaty because we detected a bug in the software after the first three sessions affecting five out of six economies of six. The bug concerned the visualization of the results at the end of some periods of Part 3. Recall that side-payments in Treaty are enacted only if both H teams fulfill the promise. The bug occurred when only one H team's effort matched the request: the left side of the screen showed the correct information (i.e., that H teams did not receive the side-payment), while the right side showed otherwise. Payoffs were computed correctly. Since robustness checks show that the bug did not have a relevant impact, we decided to use all Treaty sessions in the analyses reported in Section 4. In Section G of the Appendix, we replicate our key tables by separately analyzing economies affected by bugs and those that were not. Results remain unchanged.

[9]Including a show-up fee of 8 EUR; conversion rate 0.01 EUR = 2 tokens.

[10]We report benchmarks for the specific parameters used in the experiment. The formal proofs for a general N are available in Section A of the Appendix.

Proposition 1. ***(Social optimum with N = 2)*** *A level of global geoengineering equal to the lowest ideal point in the economy is socially optimal in all treatments.*

The socially optimal level of global geoengineering level is 2 units in economies (L, M) and (L, H) and 6 in (M, H). The intuition behind Proposition 1 relies on the linearity and symmetry of payoff losses when deviating from one's ideal point, $\lambda > 0$, and on the need to save effort cost that makes the lowest ideal point more attractive. Any combination of individual efforts g_i that sums up to that level is socially optimal because, by design, geoengineering cost α is positive.[11]

Proposition 2. ***(SPNE with N = 2)*** *The SPNE is unique in all treatments.*

- *In Baseline, the highest ideal point among decision-makers determines the level of global geoengineering. The decision-maker with the highest ideal point puts all the effort, and the other one puts in zero.*
- *In Decentralized, the lowest ideal point among decision-makers determines the level of global geoengineering. The decision-maker with the highest ideal point puts in all the effort while the other one puts in zero. Side-payments between 24 and 40 occur in economies (L, M) and (M, H), while side-payments between 48 and 80 occur in economy (L, H).*
- *In Treaty, the lowest ideal point of decision-makers determines the level of global geoengineering. The decision-maker with the highest ideal point puts in all the effort while the other puts in zero. Side-payments of 34 occur in economies (L, M) and (M, H), while side-payments of 70 tokens occur in the economy (L, H).*

The SPNE outcome outlined in Proposition 2 is not socially optimal in Baseline, while it is in Decentralized and Treaty. In Baseline, there is free-driving because the preference of the decision-maker with the highest ideal point prevails as each decision-maker has a unilateral incentive to increase the effort until the decision-makers ideal point is reached. This incentive imposes an excessive level of geoengineering on the other decision-maker. Off-equilibrium, if the decision-maker with the lowest ideal point puts some effort, it will just lower the cost of the other by inducing an equivalent decline in the effort, without any change in global geoengineering. Because efforts are substitutes, the best response of teams with lower ideal points is

[11] If α were equal to zero, then any global geoengineering level between the two ideal points would be socially optimal.

to produce nothing. Inequality is less under the SPNE outcome than under the social optimum for all economy types.[12]

To better understand the GoB platform, it could be useful to consider some analogies between Baseline treatment with $N = 2$ and a dictator game. First, the decision-maker with a high ideal point in GoB is similar to a dictator, and, in equilibrium, the decision-maker with a low ideal point keeps the outcome set by the other, as the recipient of a dictator game. Second, assigning ideal points in the GoB game is like assigning roles in the canonical dictator game. Third, final payoffs in equilibrium are very unequal. However, other design differences may suggest caution in comparing experimental results between the two games. In a GoB game, all decision-makers are active players, even though a positive effort by the low ideal point player may harm everyone.[13] Another subtle difference is the framing of the distributional conflict. In a canonical dictator game, the frame is clear: there is a fixed endowment, and one party unilaterally decides how much to give to the other, with a unique equilibrium at the corner. Instead, in the GoB game, the total surplus varies and the equilibrium solution is an interior point of the action space.

Under both the Decentralized and Treaty treatments, the decision-maker with the lowest ideal point can profit from compensating the other for reducing its effort. Besides receiving the explicit side-payment, the other will also save on the cost of geoengineering effort. Hence, the SPNE outcome is overall beneficial because total surplus surpasses that of Baseline and can be achieved because ex-ante promises are binding.

3.2 Economies of six

The predictions change under economies of six due to multilateralism. Outlined below are again the social optimum and SPNE benchmarks for each treatment.

[12]There are two reasons why inequality under SPNE is less than inequality under social optimum. First, under SPNE, the payoff of the decision-maker with the highest ideal point is decreased by its geoengineering effort cost, thereby bringing the payoffs of both decision-makers in the economy closer to each other. Second, the effort cost under the social optimum is much cheaper than under SPNE, resulting in higher differences in profits between the two decision-makers in the economy.

[13]This GoB game's feature reminds of the ultimatum game, where a punishment technology is available to the disadvantaged player (i.e., the responder), although it is typically more powerful than that available in a GoB game. Consider an ultimatum game where, for instance, the proposer keeps $9 and offers $1 to the responder. By rejecting, the responder gives up $1 and inflicts damage of $9 to the proposer. In a GoB game, this fee-to-damage ratio is around 1:1 instead of 1:9, which is less appealing because it does not lower earnings inequality in the pair and requires much stronger other-regarding preferences to be attractive.

Proposition 3. ***(Social optimum with N = 6)*** *A level of global geoengineering equal to $G = 6$ — the medium ideal point in the economy — is socially optimal in all treatments.*

This result emerges from a compromise from the presence of three diverse, equally spaced ideal points. The driving forces behind Proposition 3 are the linear losses of deviations from one's own ideal point. Notice that $\alpha < \lambda$, the cost of geoengineering plays no role in Proposition 3. At the socially optimal level, the total surplus is 716 tokens and the Gini index of inequality reaches a minimum of 0.07 if the effort is equally split by the decision-makers with a medium ideal point.

Proposition 4. ***(SPNE with N = 6 in Baseline)*** *The highest ideal point among decision-makers, $G = 10$, determines the SPNE level of global geoengineering. There exist multiple equilibria because decision-makers with the highest ideal point can share geoengineering efforts as they like. The others always put in zero effort.*

The logic leading to free-driving in Proposition 4 is the same as in Proposition 2. The predicted outcome is sub-optimal in terms of total surplus (87% of maximum) and inequality (Gini index of 0.13, when H decision-makers produce five each). Compared with economies of two, in economies of six, the decision-makers with the highest ideal point face a coordination issue on how to split the cost of effort. In this case, there exists an element of conflict similar to a battle of the sexes game.

In Proposition 4, global geoengineering is at the socially optimal level but with much higher costs of effort (72), as we have already noticed in Proposition 2. The predicted outcome is sub-optimal in terms of total surplus (66% of the social optimum) and increases inequality (Gini index of 0.13 vs. 0.05, when M decision-makers produce three each). Decision-makers with ideal points at each end of the spectrum have clear strategies to cancel each other with their choices. Those with intermediate ideal points are pivotal here. They also face a coordination issue about how they should split the cost of effort.

Proposition 5. ***(SPNE with N = 6 in Decentralized and Treaty)*** *There exists multiple SPNE:*

- *Free-driving equilibria in Decentralized and Treaty: As in Baseline, there exist multiple equilibria without side-payments leading to the inefficient outcome $G = 10$.*

- *Side-payments equilibria in Decentralized: There exist multiple equilibria characterized by the socially optimal outcome $G = 6$ and involving side-payments. These equilibria prescribe two out of four decision-makers with either low or medium ideal points to promise a side-payment of any* *amount between 32 to 40 tokens (inclusive of 32 and 40) to the decision-makers with the highest ideal point in exchange for a total effort of 6. Both high ideal point decision-makers should receive a side-payment for an effort of 3 each.*

- *Side-payments equilibria in Treaty: There exist six equilibria characterized by the socially optimal outcome $G = 6$ and involving side-payments. These equilibria prescribe two out of four decision-makers with either low or medium ideal points to promise a side-payment of 34 tokens to the decision-makers with the highest ideal point in exchange for an effort of 3 each.*

In Proposition 5 the equilibrium set is richer than in any other treatment (Table 1). In a free-driving equilibrium, no promise is made and the outcome is identical to that of the Baseline. This outcome is possible because, by design, a decision-maker is incapable of *individually* promising a side-payment that is sizable enough to convince high ideal point teams to reduce their effort. This set of equilibria is Pareto inferior to the ones with side-payments. Moreover, it is not coalition stable, as the joint promise of two decision-makers can move the economy to an equilibrium with side-payments.[14]

Consider now the equilibria with side-payments. The structure of promises in the design simplifies coordination between decision-makers with the highest ideal point as it requires an effort of 3 to each. At the same time, it also raises a new issue of coordination among the four decision-makers who can make promises because any combination of two decision-makers offering treaties for the same level of production can achieve the socially optimal level: (L_1, L_2), (L_1, M_1), (L_1, M_2), (L_2, M_1), (L_2, M_2), and (M_1, M_2). The situation bears similarities to the battle of the sexes, but it appears behaviorally more difficult as four heterogeneous agents are involved.[15]

[14] As discussed in Medema (2020), coalition formulation can undermine the effectiveness of the Coasian bargaining in achieving efficiency.

[15] In an equilibrium with side-payments, levels of productions below the socially optimal one cannot be reached. Consider, for example, a case where the two low ideal point decision-makers promise a side-payment of 70 each in exchange for the global production of two. The high ideal point countries would find it profitable to adjust their production to satisfy such a request. However, either one of the intermediate ideal point countries would have an *individual* incentive to increase its production to reach global production of six.

4 Results

We put forward the main results and discuss the likely mechanisms and behavioral drivers behind them.[16]

4.1 Aggregate results

Before presenting Results 1 and 2 about side-payments, we report key statistics for the Baseline treatment. In Baseline, the data strongly support the free-driving hypothesis (Proposition 2). The modal global geoengineering level corresponded to the SPNE outcome both in economies of two and six, which is suboptimal (Figure E.1 in Appendix, Figure 2). Moreover, again in line with Proposition 2, in economies of two, those teams with high ideal point provided on average 91% of the total effort in the economy. The analogous figure for economies of six is 86% (Figure E.4 in Appendix). The data for Baseline is the same used in Abatayo et al. (2020) to address a different research question.

We report next about the aggregate effects of side-payments on global geoengineering, total surplus, and inequality.

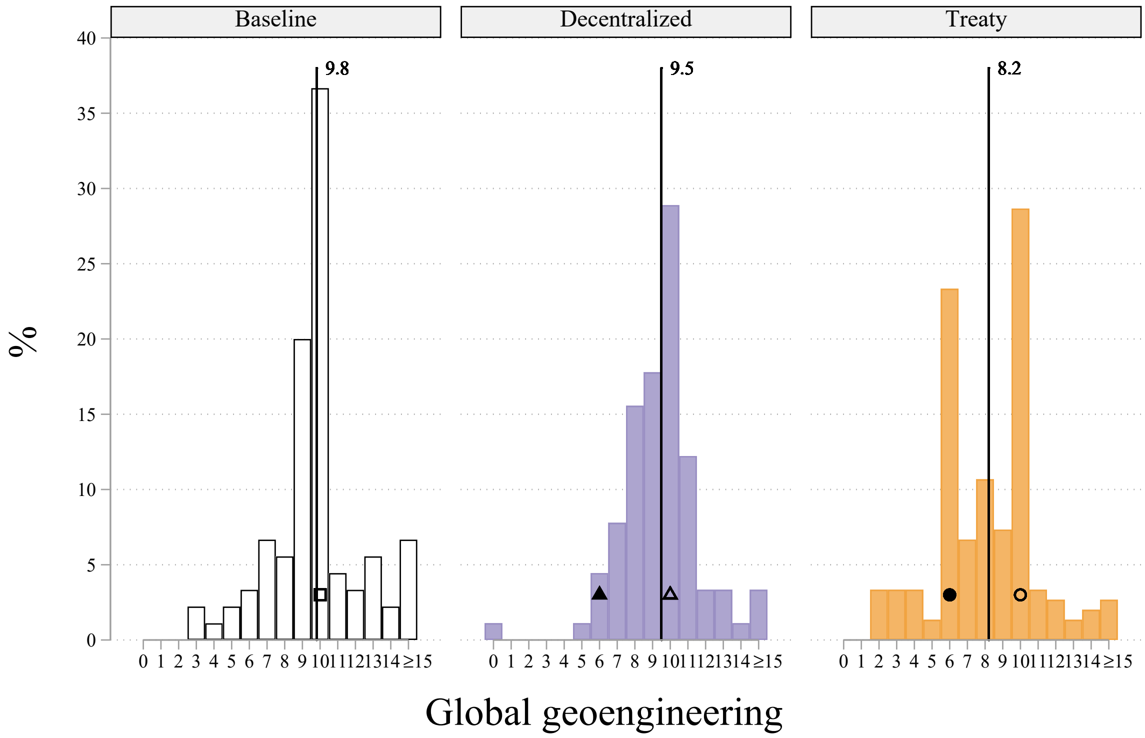
Result 1. *Treaty and Decentralized had a modest impact in reducing the free-driving observed in Baseline.*

Support for Result 1 is in Figure 2 and Table 2. We first report findings for economies of six. On average, global geoengineering was 9.8 in Baseline, 9.5 in Decentralized, and 8.2 in Treaty.[17] According to Wilcoxon-Mann-Whitney tests (Table 2), the reduction in average global geoengineering with respect to Baseline is statistically significant for Treaty ($p = 0.020$, 16 obs.), but not for Decentralized ($p = 0.228$, 12 obs.). As in Baseline, the modal outcome in terms of global geoengineering corresponded to the free-driving outcome of 10 in both Decentralized and Treaty (Figure 2). However, global geoengineering distributions in these treatments were slightly more skewed towards lower outcomes than in Baseline. This pattern is especially visible in Treaty, where the second most frequent global geoengineering outcome was 6, which corresponds to the socially optimal level.

[16] In all our analyses, we consider teams as the decision-making unit. Hence, we collapsed subject-level data at the team-level. We report an analysis of within-team disagreements in Section D of the Appendix.

[17] In all treatments, average global geoengineering was relatively stable across periods. Levels in Treaty were lower than levels in Baseline in all periods (Figure E.2b in the Appendix).

Figure 2: Global geoengineering in economies of six



Notes: Vertical lines mark average global geoengineering levels by treatment. Solid markers indicate the equilibrium predictions with side-payments; hollow markers indicate equilibrium predictions without side-payments (free-driving). An observation is one economy in a period of Part 3.

Lower levels of global geoengineering in Treaty positively reflected on the total surplus, computed as the sum of all teams' earnings in an economy in a period, which was 8 percentage points higher than that in Baseline and statistically significantly so ($p = 0.030$, 16 obs.). Instead, the social surplus in Decentralized was only 3 percentage points higher than that in Baseline, and the difference is not statistically significant ($p = 0.749$, 12 obs.). Neither Decentralized nor Treaty had a statistically significant impact on inequality, as measured by the Gini index calculated on cumulative earnings in an economy at the end interaction ($p \geq 0.129$, 12 and 16 obs., respectively).

Patterns in economies of two confirm the evidence from economies of six. When pooling data from all types of economies in Part 2, a series of Wilcoxon-Mann-Whitney tests fail to detect a treatment effect of Decentralized on any of the three outcomes of interest (Table 2; $p =$

Table 2: Descriptive statistics and tests of economy-level variables

	Baseline	Decentralized		Treaty	
	Mean (S.D.)	Mean (S.D.)	p-value	Mean (S.D.)	p-value
Part 1					
Global geoengineering	8.133 (1.922)	8.078 (1.577)	0.812	8.200 (2.037)	0.848
Total surplus	205.467 (26.803)	207.244 (24.353)	0.800	203.867 (29.274)	0.741
Gini index	0.051 (0.040)	0.051 (0.031)	0.704	0.046 (0.043)	0.594
Observations	18	18		30	
Part 2					
Global geoengineering	8.289 (2.229)	8.033 (2.252)	0.506	6.327 (2.683)	0.020
Total surplus	203.067 (35.624)	197.867 (38.602)	0.635	215.627 (34.192)	0.166
Gini index	0.051 (0.044)	0.055 (0.028)	0.359	0.046 (0.045)	0.565
Observations	18	18		30	
Part 3					
Global geoengineering	9.844 (0.986)	9.500 (0.530)	0.228	8.240 (1.419)	0.020
Total surplus	586.400 (41.675)	605.333 (30.198)	0.522	632.640 (42.948)	0.030
Gini index	0.088 (0.017)	0.092 (0.013)	0.749	0.078 (0.017)	0.129
Observations	6	6		10	

Notes: p-values refer to Wilcoxon-Mann-Whitney exact tests of Baseline vs. Decentralized and Baseline vs. Treaty. The null hypothesis is that the samples come from the same population. One observation corresponds to an economy in Part 3; one observation is the average of the three types of economy in Parts 1 and 2. Global geoengineering and Total surplus are computed as the average outcome in an economy in a Part; the Gini index is computed on cumulative earnings in the last period of each Part.

0.506 for global geoengineering, $p = 0.635$ for total surplus, $p = 0.359$ for inequality).[18] Instead, we identify a negative and statistically significant effect of Treaty on global geoengineering ($p = 0.020$), but not on the other two dimensions ($p = 0.166$ for total surplus, $p = 0.565$ for inequality).[19]

Overall, Treaty was more effective than Decentralized in limiting global geoengineering. Under $N = 6$, two aspects set Decentralized and Treaty apart. On the one hand, the institutional setting: in Decentralized only bilateral side-payments are available, while in Treaty, it is possible to establish a geoengineering treaty. On the other hand, the promise space is wider in Decentralized than in Treaty. With our design, we can test how each aspect contributed to achieving more efficient outcomes in Treaty. A first insight comes from the observation that in Part 2 with $N = 2$, where Decentralized and Treaty only differ in the promise space width,

[18]As a robustness check, we implemented one session of Decentralized where instead of playing Part 3 in economies of six, teams played additional 15 periods in economies of two. This data suggests that even after substantial learning in the simple setting of economies of two, decentralized side-payments were rather unsuccessful at mitigating free-driving (see Figure E.3 in Appendix).

[19]For both $N = 6$ and $N = 2$, linear regressions with random effects and clustered standard errors at economy-level corroborate results from non-parametric tests (Tables F.1 and F.2 in the Appendix).

Treaty already outperformed Decentralized in a statistically significant way ($p = 0.003$, see Wald test in Table F.2 in the Appendix).

A difference-in-difference approach can provide a formal test of the relative importance of the institutional setting versus the promise space width. If the better performance of Treaty in Part 3 is due to its institutional setting, we should expect the improvement to show when going from Part 2 to Part 3 for Treaty more than for Decentralized. Instead, if the promise space width is key, the observed difference when moving from Part 2 to Part 3 will be roughly the same for Decentralized and Treaty. The evidence supports the latter interpretation, showing a prevalent role for the width of the promise space in driving the global geoengineering differences between Decentralized and Treaty. The estimated coefficient of the difference-in-difference is small and statistically insignificant ($\beta = -0.447$ and $p = 0.394$ according to linear regression with random effects and clustered standard errors at the economy-level). This evidence does not necessarily imply that multilateralism plays no role, given that in both Decentralized and Treaty, efficiency was relatively low, especially under $N = 6$. Analyses of side-payments reported in the next results will add more elements to the picture.

Table 3: Overall frequency of promises and side-payments

	Outcome	Frequency				Promise pattern
		Decentralized		Treaty		
$N = 2$	No side-payments	71%	13 (14%)	52%	48 (32%)	No promise
			51 (57%)		30 (20%)	Promise not fulfilled
	With side-payments	29%	19 (21%)	48%	72 (48%)	From team w/lowest ideal point
			7 (8%)		–	From team w/highest ideal point
			90 (100%)		150 (100%)	
$N = 6$	No side-payments	32%	3 (3%)	72%	19 (13%)	No promise
			26 (29%)		88 (59%)	Promise not fulfilled
	With side-payments	68%	36 (40%)	28%	8 (5%)	From one team
			20 (22%)		29 (19%)	From two teams
			5 (6%)		6 (4%)	From more than two teams
			90 (100%)		150 (100%)	

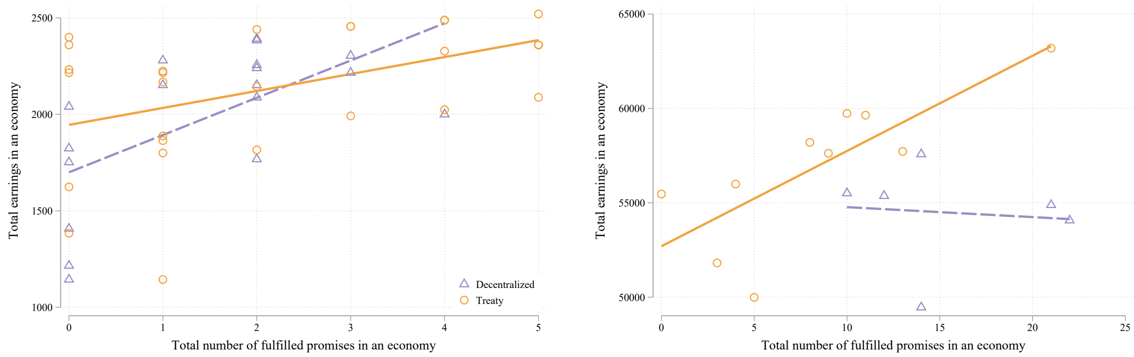
Notes: One observation corresponds to one economy in a period. Teams with the highest ideal point could make promises only in the Decentralized treatment. In economies of six where two promises were made, they most often came from the two M teams in Treaty and from one L team and one M team in Decentralized. under $N = 6$, 93 side-payments occurred in Decentralized and 84 side-payments occurred in Treaty.

Result 2. *Economies with more side-payments tended to reach higher total surplus.*

Evidence for Result 2 comes from Table 3 and Figure 3. Side-payments were enacted, but much less frequently than predicted. Theory predicts they would be used in 100% of the economies in both Decentralized and Treaty (Propositions 2, 4, and 5).[20] Table 3 takes as a unit of observation an economy in a period and shows that, under $N = 2$, a side-payment was enacted in about a third of the observations in Decentralized (29%) and about half of the observations in Treaty (48%). These patterns are almost flipped under $N = 6$, where the percentage of observations where at least one side-payment was enacted raises to more than two thirds in Decentralized (68%), while it shrinks to less than one third in Treaty (28%).

Figure 3: Higher total earnings with more fulfilled promises

(a) $N = 2$ **(b)** $N = 6$



Notes: The dashed (solid) line shows the linear prediction in Decentralized (Treaty). One observation corresponds to an economy at the end of Part 2 panel (a) and Part 3 in panel (b): for $N = 2$, 18 obs. in Decentralized and 30 obs. for Treaty; for $N = 6$, 6 obs. in Decentralized and 10 obs. in Treaty.

Next, we report the correlation between the frequency of fulfilled promises and aggregate surplus in the economy within each treatment condition. Figure 3 illustrates a scatter plot of the cumulated number of side-payments vs. aggregate earnings, including a line of best fit. For $N = 2$, there is a statistically significant and positive relation in both Decentralized and Treaty treatments ($p = 0.006$ and $p = 0.007$, respectively). For $N = 6$, the correlation is clearly significant and positive in Treaty ($p = 0.008$), while it is insignificant and flat in Decentralized ($p = 0.858$). Thus, in Treaty under $N = 6$, there were fewer but more effective side-payments as compared to Decentralized. The reason can be rooted in the coordination complexity characterizing the Decentralized treatment with $N = 6$. Recall that, in order to achieve the social optimum, two side-payments are necessary. While every single promise in Treaty targeted by design both H teams, in Decentralized the promise senders had to coordinate on whom to target. Of the 53 cases where at least two promises to H teams were made in an

[20] For $N = 6$, we refer to the side-payments equilibria.

economy of Decentralized, in 36% of them, only one of the two H teams was targeted. This evidence highlights the lack of coordination among promise senders and can also explain why global geoengineering was on average higher in Decentralized than in Treaty (Table 2).

4.2 Why were side-payments so infrequent?

Three possible obstacles could have intervened and resulted in few side-payments. First, few promises were formulated in the first place. Second, the promises formulated were not mutually beneficial or otherwise unattractive. Third, even profitable promises were turned down by the recipients. In this section, we explore the empirical relevance of each of these obstacles.

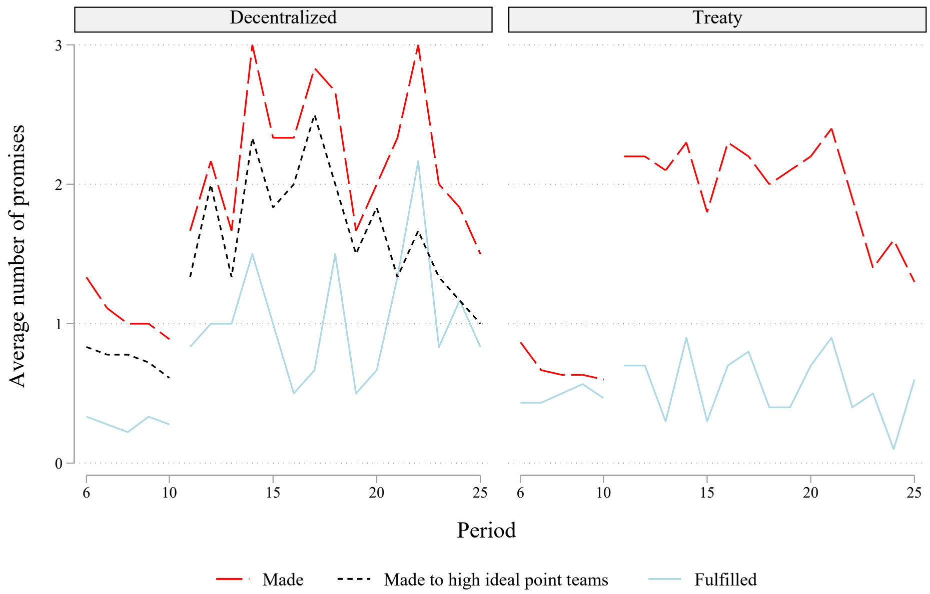
Result 3. *In both Decentralized and Treaty, there were many promises under $N = 2$ and $N = 6$.*

Evidence for Result 3 comes from Table 3 and Figure 4. Without side-payments, the equilibrium outcome in Decentralized and Treaty with $N = 6$ is free-driving. Therefore, the absence of promises could be an indication of economies coordinating on such an equilibrium. On the contrary, our data suggest that decision-makers were trying to get away from it: only in 3% of cases in Decentralized and 13% of cases in Treaty no promise was made (Table 3, $N = 6$). Usually, one or more promises were made, although none were fulfilled with some frequency (58% in Treaty and 30% in Decentralized). Hence, for $N = 6$, the lack of promises does not seem a primary reason why side-payments were not enacted. Similar patterns emerged under $N = 2$ as the cases without any promise were 14% in Decentralized and 32% in Treaty. Among the promises made, those that went unfulfilled were 63% in Decentralized and 20% in Treaty.

Figure 4 provides more details by showing the absolute number of promises and side-payments over time in an average economy of Treaty and Decentralized. In economies of six (periods 11-25), there were on average more promises than in economies of two (periods 6-10), which is the likely outcome of the simple mechanical reason of having more teams that can make promises. In both treatments, to support the socially optimal equilibrium, theory predicts one side-payment for $N = 2$ and two side-payments for $N = 6$. As already noted, the actual numbers of side-payments (i.e., fulfilled promises) are below those predicted and exhibit a relatively stable trend.

The trend in the number of promises is approximately flat or declining over time in all conditions and treatments. To facilitate treatment comparisons in Figure 4, we added an extra line for the Decentralized treatment representing the subset of promises made by decision-

Figure 4: Promises and side-payments over time



Notes: Economies of two in periods 6 to 10 (Part 2) and economies of six in periods 11 to 25 (Part 3). One observation corresponds to one economy in a period.

makers with the lowest ideal point toward those with the highest ideal point.[21]

Next, we will look at the type of promises made to understand what went wrong, with particular attention to the incentive-compatibility of the promise. The analyses will focus on $N = 2$ data because it can provide the cleanest test. Assessing a promise's profitability under $N = 6$ is complex for at least three reasons. First, the ex-post evaluation of a promise should take into account also the promises made by others. Second, given that promises were made simultaneously, ex-ante, there exists considerable strategic uncertainty on the other teams' strategies. Third, the presence of multiple teams with the same ideal point raises an issue of coordination. These reasons are absent or less important under $N = 2$.

Result 4. *While promises were generally profitable for senders, many were unprofitable for the recipients, especially in Decentralized.*

Support for Result 4 is in Figure 5. We define a promise as profitable when, if fulfilled, it yields a payoff for both sender and recipient that is higher or equal to the payoff from the

[21]We consider only promises from one decision-maker to another under $N = 2$, and from four decision-makers to the other two under $N = 6$. This restriction mimics the rules for Treaty, where high ideal point teams were not allowed to make promises to low ideal point teams.

free-driving equilibrium in the Baseline treatment.[22] When considering only promises to high ideal point teams in the experiment under $N = 2$, the overwhelming majority of promises were profitable for their senders (88% in Decentralized and 89% in Treaty). Were promises also generally profitable for their recipient? there is a substantial treatment difference: 28% in Decentralized and 79% in Treaty. All in all, mutually beneficial promises represented 21% of the total number of promises in Decentralized and 76% of the total number of in Treaty. Hence, while there was usually no shortage of promises in terms of number, their quality was a key issue in the Decentralized treatment, and much less so in Treaty.

Figure 5 provides more detailed evidence about the patterns of promises in each type of $N = 2$ economy. Each panel shows a scatter plot of the promised amount versus the requested effort. The shaded area in the graphs indicates promises that were unprofitable for the recipient. In the following result, we investigate which types of promises were more likely to be fulfilled by recipients.

Result 5. *Many profitable promises went unfulfilled in Decentralized and only some in Treaty.*

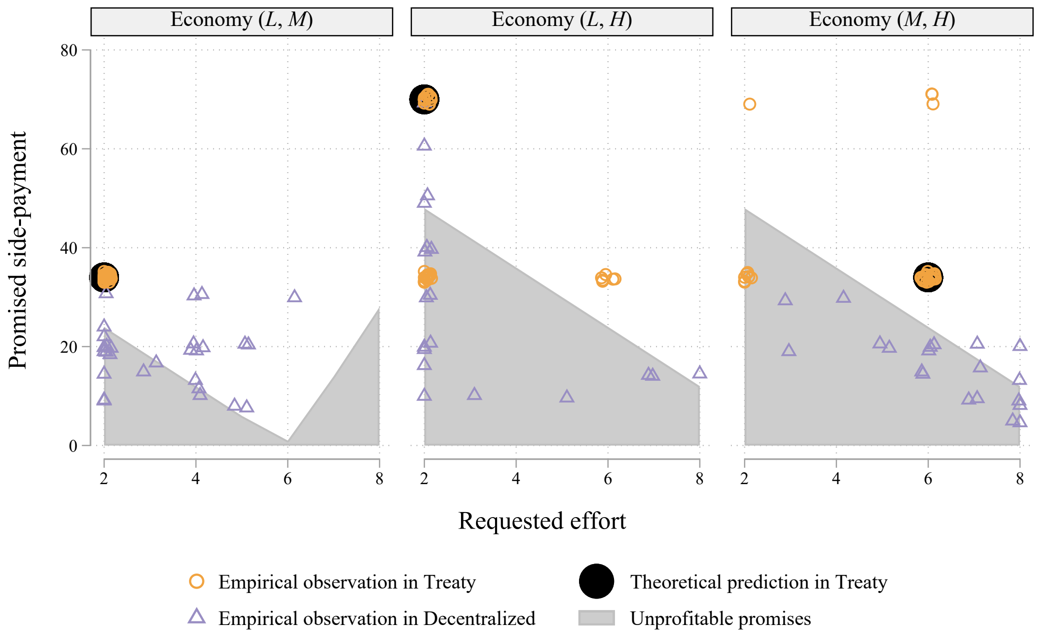
In the Decentralized treatment, 58% of promises that were profitable for the high ideal point teams were fulfilled (11 out of 19). The analogous figure for the Treaty treatment was 82% (66 out of 81). Hence, the recipients (high ideal point teams) were also partially responsible for the low number of side-payments enacted in the experiment. If we focus on mutually profitable promises, patterns remain similar, with a fulfillment rate of 43% in Treaty (6 out of 14) and 81% in Decentralized (62 out of 77). Finally, in a minority of cases, recipients also fulfilled promises unprofitable for themselves (17% in Decentralized and 29% in Treaty).

4.3 Behavioral drivers

This section explores how different behavioral drivers might have affected teams' decisions during the experiment. The aim is to shed some light on the factors that ultimately led to the empirical patterns reported so far. Specifically, we consider three behavioral underpinnings: (1) confusion, (2) size of the stakes, and (3) social preferences. Data from economies of two

[22]When we evaluate promises' profitability in the Decentralized treatment, to account for the fact that teams could also request an effort *greater* or *smaller* than a certain level, we make the following assumptions. When a team requests an effort smaller than a given level, we assume that the high ideal point team that receives the promise will exert the maximum effort that allows to fulfill the promise (to minimize the loss from the deviation from its ideal point). When a team requests an effort greater than a given level, we assume that the high ideal point team produces at its ideal point. See the note to Figure 5 for more details.

Figure 5: Were promises profitable for the recipient?



Notes: One observation corresponds to a promise made by a low ideal point team in a period to a high ideal point team. In Decentralized, if the low ideal point team requested was an effort *lower* a certain value (32 observations), the requested effort was re-coded as the request effort minus 1 (i.e., the most profitable effort for the high ideal point team that still allows fulfilling the promise); if the low ideal point team requested an effort *greater* a certain value (1 observation), the requested effort was re-coded as equal to the ideal point of the high ideal point team. Observations were jittered to display them better.

provide the cleanest test.

Confusion. Previous experimental evidence suggests that teams are generally more rational players than individuals deciding in isolation. In our experiment, we use two cues to detect confusion: the behavioral reaction of teams to changing strategic situation and the quiz about the understanding of experimental instructions. An analysis of our data suggests that participants have a rather good understanding of the strategic situation. We support this statement using two analyses on the experimental data, which focus on economies of two under the Baseline rules and on the behavioral change of decision-makers when moving from an economy of two into an economy of six: in both cases, teams' behavior is in line with the theoretical predictions.[23]

We check if a team's level of understanding of the instructions correlates with the quality

[23]See more details in Section C of the Appendix.

of decisions concerning side-payments. We employed a series of probit regressions to explain why teams make a promise or fulfill a promise. Among the regressors, we place the average number of wrong answers that the two team members gave in the control questions on the instructions (Table 4).[24] We report that confused teams were less likely to make a promise, regardless if we consider all promises or just those profitable for the sender. Lack of promises was not though the key obstacle to side-payments.

Table 4: Factors behind making and fulfilling a promise for $N = 2$

	Make a promise		Make a promise profitable for sender		Fulfill a promise	
	Decentralized (1)	Treaty (2)	Decentralized (3)	Treaty (4)	Decentralized (5)	Treaty (6)
Mistakes in quiz of Parts 1 and 2	-0.141**	-0.215***	-0.123*	-0.209***	-0.091	0.004
	(0.065)	(0.050)	(0.072)	(0.053)	(0.075)	(0.055)
Negative reciprocity	-0.023	-0.029	0.006	-0.003	-0.054	0.081***
	(0.027)	(0.034)	(0.030)	(0.040)	(0.034)	(0.027)
Altruism	0.000	-0.002*	0.001	-0.001	0.001	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Proneness to risk taking	0.043	-0.021	0.101**	-0.030	0.026	0.017
	(0.027)	(0.031)	(0.047)	(0.040)	(0.041)	(0.042)
Requested effort					0.063**	0.028
					(0.028)	(0.030)
Promised side-payment					0.004	0.013***
					(0.004)	(0.002)
Period number (6 to 10)	-0.050**	-0.057***	-0.030*	-0.028	-0.002	0.068***
	(0.021)	(0.019)	(0.017)	(0.021)	(0.031)	(0.020)
Economy (L, H)	-0.176**	0.028	-0.076	0.013	-0.168*	-0.427***
	(0.081)	(0.103)	(0.073)	(0.108)	(0.092)	(0.071)
Economy (M, H)	-0.051	-0.118	0.042	-0.307**	-0.157*	-0.075
	(0.075)	(0.134)	(0.097)	(0.145)	(0.085)	(0.085)
$(L, H) - (M, H)$ economy	-0.125	0.147	-0.118	0.320**	-0.011	-0.352***
	(0.087)	(0.131)	(0.087)	(0.146)	(0.092)	(0.085)
Observations	180	150	180	150	96	102

Notes: Marginal effects from probit regressions with clustered standard errors at economy-level. One observation corresponds to a team in a period in Part 2. The variables *Negative reciprocity*, *Altruism*, *Proneness to risk-taking*, and *Number of mistakes in for Parts 1 and 2* are subject-specific and were here averaged at team-level. *Negative reciprocity* and *Altruism* were constructed following Falk et al. (2018) using items 4, 5, and 6, and items 2 and 3, respectively, in the final questionnaire; *Proneness to risk taking* corresponds to item 1 in the final questionnaire, respectively (Section B.3 in the Appendix). *Number of mistakes in for Parts 1 and 2* is equal to the total number of mistakes made by a subject in Parts 1 and 2 of the experiment (Section B.2 in the Appendix).

Stakes. A possible concern about our design is that stakes were too small to motivate teams to use side-payments efficiently. By stake, we intend the payoff difference between being at the socially optimal outcome versus the free-driving outcome. To this end, we exploit variations in

[24] All regressions include controls for social and risk preferences, type of economy, and period number.

stake level among economies of two in shaping promise decisions. Consider an L team either in an economy (L, H) or (L, M). In both economies, the L team will is the worst off, but the damage from free-driving is more severe in (L, H) economies than in (L, M) economies. Hence, we conjecture that making promises is more salient in (L, H) because stakes are higher than in the other economies of two.

We study this conjecture through the regressions in Table 4, where the default category is the (L, M) economy, and there are dummies for the other types of economies. We expect the likelihood of making a promise to be highest where stakes are highest, that is, a positive coefficient for the dummy (L, H) economy. The evidence does not support this conjecture: the estimate is negative and significant in Decentralized and close to zero in Treaty. Hence, the evidence suggests that the size of the stake was not crucial in shaping the decision to make a promise. When considering the decision to fulfill the promise, the dummy (L, H) economy is again negative. This evidence contrasts with the conjecture that high ideal point teams might be more willing to fulfill promises when this is very beneficial to the low ideal point team they are matched with. A possible rationale for the fact that the economy where teams were both more likely to make and fulfill promises was (L, M), could be that this economy was characterized by a socially optimal outcome with the lowest inequality level (see Table 1).

Social preferences. In the GoB game, altruistic concerns might lead high ideal point teams to fulfill promises which are not fully compensatory. We have reported instances of this behavior in the discussion of Result 5. Moreover, low ideal point teams — who are by institutional design those who are worse-off — may dislike paying others to slightly improve their position. Low ideal point teams may perceive the free-driving behavior of the high ideal point team as unkind and hence refrain from formulating promises because such instruments entail further benefiting the other. We assess the role of two self-reported measures of social preferences elicited in the final questionnaire, about altruism and the propensity of a team to engage in retaliatory behavior or punishing behavior when treated unjustly.[25] None of our social preferences proxies seems to be particularly relevant in shaping decisions to either make or fulfill a promise (Table 4). The magnitude of the estimated coefficients is generally very small, with the exception of fulfilling a promise in Treaty, where the sign of the negative reciprocity variable is the opposite of what we would expect.

[25] We used items from the experimentally validated survey designed by Falk et al. (2018).

5 Conclusion

Solar geoengineering is a technique that can reconfigure the strategic relations among countries when it comes to the economics and politics of climate change. At this stage, any consideration is speculative because of the absence of any large-scale implementation of geoengineering. We designed and ran a laboratory experiment that can provide insights into geoengineering governance.

More specifically, we study the possible use of side-payments as an instrument to avoid free-driving, which is the unilateral deployment of geoengineering at levels that excessively cool Earth's temperature (Weitzman, 2015). Given the divergent goals of decision-makers, side-payment could, in principle, allow achieving socially efficient use of climate geoengineering.

According to the Coase theorem, conditional transfers from one party to another are a way for damaged parties to limit their losses by influencing the behavior of those who have a right to act. In situations with low transaction costs and perfect information, as the one studied here, this type of voluntary agreements are expected to be welfare-improving. In the absence of a governing institution, past experiments confirmed the strong attraction toward free-driving (Abatayo et al., 2020). Our research question is about the empirical effectiveness of side-payments in containing the overuse of geoengineering.

Laboratory studies of the Coase theorem generally show that the parties reach a beneficial agreement in simple settings (see the seminal experiments of Hoffman and Spitzer, 1982, 1985; Harrison and McKee, 1985). Some studies looked at more involved settings with the possibility of bilateral monetary transfers (Andreoni and Varian, 1999) and also reported substantial improvement in the efficiency. In another study, Charness et al. (2007) report that side-payments increase cooperation in a prisoner's dilemma from 14.7% to 55.3%. Others report more limited efficiency gains, either because of the complex environment (Hamaguchi et al., 2003) or for the presence of endowment effects (Kahneman et al., 1990).

Our empirical results in the context of the public good-or-bad game by Weitzman (2015) do not support a full Coasian bargaining solution. Although aggregate efficiency improves, the gain is small compared to the Baseline without side-payments (3%-5% of total surplus). This pattern appears in all four conditions studied, where we varied the economy size and the institutional rules for side-payments. Why was the effectiveness of side-payment limited? Not enough side-payments took place — 28%-64% depending on the treatment instead of 100% — and even when side-payments were enacted, they were not effective enough in reducing the aggregate level of geoengineering.

Three main conclusions emerge. First, the performance of side-payments was much worse than expected even in laboratory economies of two. The reasons for the frequent failure to attain efficiency remain unclear. According to our exploratory analyses, behavioral drivers such as confusion, social preferences, and low stakes do not explain this empirical result. Other behavioral factors like the endowment effects could have played a role, but the current experiment was not designed to test it properly.[26]

Second, a major issue underlying the result is the coordination failure in the negotiation process over side-payments. The clearest evidence comes from the multilateral setting of the Decentralized treatment: most side-payments were carried out by a single decision-maker in the economy, which was insufficient to control the efforts of the high-ideal point decision-makers.

Third, the institutional framework of Treaty performed better than that of Decentralized. One lesson of the experiment is about the necessity to provide structure to the negotiation, as the Pareto-dominant equilibrium will not be selected unless proper institutional forces channel subjects toward it. Economic theory is silent on the point, but this study is a warning that lack of proper communication and wide strategy spaces typical of international negotiation may pose problems for a successful implementation of side-payment schemes.

In the field, including that of international climate negotiations, complexity is likely to be even higher than what was simulated in this experiment. In the experiment, there was perfect information about all players' ideal points and all proposed side-payments. Furthermore, the maximum number of parties was six rather than hundreds. Such considerations suggest care in creating conditions to enable side-payments to be more successful. Communication among decision-makers, which is possible in the field but not in our experiment, might help reduce some of these complexities and improve coordination. However, its effectiveness in a strategic context characterized by many heterogeneous decision-makers is not trivial and boils down to an empirical question, which we plan to investigate in future research.

[26] For instance, high ideal point teams might develop a sort of entitlement of a level of geoengineering equal to their ideal point, and hence they require a side-payment higher than predicted to reduce their effort.

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Appendix

A Proofs

Without loss of generality, assume that teams $i = 1, 2, \ldots, n$ have the following ideal geoengineering points: $G_1^* \leq G_2^* \leq \cdots \leq G_n^*$ and that each team has the following profit function:

$$\pi_i = E - \alpha|g_i| - \lambda|G - G_i^*|$$

where g_i is the amount of geoengineering team i produces and $G = \sum_{i=1}^{n} g_i$.

A.1 Social Optimum

We assume the social planner to maximize the unweighted sum of all teams' payoffs:[1]

$$\Pi = \sum_{i=1}^{n} \pi_i = nE - \alpha \sum_{i=1}^{n} g_i - \lambda(|G - G_1^*| + |G - G_2^*| + \ldots + |G - G_n^*|),$$

which can be rewritten as:

$$\Pi = \sum_{i=1}^{n} \pi_i = nE - \alpha G - \lambda \sum_{i=1}^{n} |G - G_i^*|,$$

We can also recast the planner's problem into the following minimization problem:

$$\min_G \{f(G)\} = \min_G \left\{ \alpha G + \lambda \sum_{i=1}^{n} |G - G_i^*| \right\} \tag{A.1}$$

To find the value of G that minimizes $f(G)$, we will need to use the following theorem:

Theorem 1. *For any two numbers x_1 and x_2, where $x_1 \leq x_2$, the sum of the absolute values of the deviations is minimum when when $x_1 \leq \theta \leq x_2$.*

Proof. Consider two numbers, x_1 and x_2, where $x_1 \leq x_2$:

(a.) for any θ where $x_1 \leq \theta \leq x_2$, $\sum_{i=1}^{2} |\theta - x_i| = (\theta - x_1) + (x_2 - \theta) = x_2 - x_1$,

(a.) for any θ where $\theta \leq x_1$, $\sum_{i=1}^{2} |\theta - x_i| = (x_1 - \theta) + (x_2 - \theta) = x_2 + x_1 - 2\theta$,

(a.) for any θ where $\theta \geq x_2$, $\sum_{i=1}^{2} |\theta - x_i| = (\theta - x_1) + (\theta - x_2) = 2\theta - x_2 - x_1$.

Note that in (b), $x_2 + x_1 - 2\theta > x_2 + x_1 - 2x_1 = x_2 - x_1$. Also note that in (c), $2\theta - x_2 - x_1 > 2x_2 - x_2 - x_1 = x_2 - x_1$. Hence, for any two numbers x_1 and x_2, where $x_1 \leq x_2$, the sum of the absolute values of the deviations is minimum when when $x_1 \leq \theta \leq x_2$. □

[1] Who bears the cost of geoengineering does not matter here, as long social welfare is maximized.

We focus here on the case where we have an even number of teams, as in our experiment.[2] Note that we can rewrite the term $\sum_{i=1}^{n} |G - G_i^*|$ in equation A.1 as follows:

$$|G_1^* - G| + |G_2^* - G| + \ldots + |G_{\frac{n}{2}}^* - G| + |G_{\frac{n}{2}+1}^* - G| + \ldots + |G_{n-1}^* - G| + |G_n^* - G|.$$

Rearranging terms by pairing up the smallest and largest G_i^*, we will have:

$$(|G_1^* - G| + |G_n^* - G|) + (|G_2^* - G| + |G_{n-1}^* - G|) + \ldots + (|G_{\frac{n}{2}}^* - G| + |G_{\frac{n}{2}+1}^* - G|).$$

This can further be rewritten as:

$$\sum_{i \in \{1,n\}} |G_i^* - G| + \sum_{i \in \{2,n-1\}} |G_i^* - G| + \ldots + \sum_{i \in \{\frac{n}{2},\frac{n}{2}+1\}} |G_i^* - G|.$$

Using Theorem 1, we know that for any two numbers $G_h^* < G_k^*$, the sum of the absolute values of the deviations between these two numbers and a constant, G, is minimized when $G_h^* \leq G \leq G_k^*$. As such, we are looking for a G that is within all these intervals: $[G_1^*, G_N^*], [G_2^*, G_{n-1}^*], \ldots, [G_{\frac{n}{2}}^*, g_{\frac{n}{2}+1}^*]$.

There is a range of numbers that are elements of all intervals listed above. Any number between (and including) $G_{\frac{n}{2}}^*$ and $G_{\frac{n}{2}+1}^*$ satisfy the conditions in Theorem 1 for all intervals. Does this mean that the solution to equation A.1 is any number between $G_{\frac{n}{2}}^*$ and $G_{\frac{n}{2}+1}^*$?

No. $f(G)$ is composed of two terms: the α-term and the λ-term. While any number between $G_{\frac{n}{2}}^*$ and $G_{\frac{n}{2}+1}^*$ minimizes the λ-term, only one number in the closed interval $[G_{\frac{n}{2}}^*, g_{\frac{n}{2}+1}^*]$ minimizes the α-term, i.e. the minimum of all numbers in the interval $G_{\frac{n}{2}}^*$ and $G_{\frac{n}{2}+1}^*$. Hence, the only number that minimizes $f(G)$ is $G_{\frac{n}{2}}$.

A.2 Equilibria in Baseline

First, notice that any strategy prescribing a production $g_i > g_i^* \ \forall i \in N$ is a dominated strategy and hence can be ignored. For simplicity, we focus first on the case where all teams have a different ideal point and can be ranked from 1 to n based on it. Consider a team j with ideal point G_j^* who wants to reach its ideal production level. Team j has an incentive to choose $g_j = G_j^*$ because the marginal cost benefit from producing an extra unit, λ, is larger than than the marginal cost of production, α, when $G < G_j^*$. All teams with ideal points below G_j^* will not produce anything, in order to not aggravate the problem of being already beyond their ideal level. Consider now team $j+1$ with an ideal point $G_{j+1}^* > G_j^*$ who also wants to reach its ideal production level. Anticipating that G_{j+1}^* will geoengineer at G_{j+1}^*, team j will not geoengineer. Doing this recursively for all teams with ideal points above G_{j+1}^*, we will find that all teams with ideal points below G_n^*, will not geoengineer. Hence,

$$g_i^{Baseline} = \begin{cases} 0, & \forall i < n \\ G_n^*, & \text{otherwise} \end{cases}$$

Now, consider the case where two or more teams share the same ideal point G_n^*. All production combinations by teams with ideal points G_n^* that sum up to a global production of $G = G_n^*$ constitute an equilibrium. Since the marginal cost benefit from producing an extra unit, λ, is

[2] The result is slightly different if the total number of teams is odd.

larger than than the marginal cost of production, α, a team with an ideal point G_n^* will always have an incentive to produce, regardless of what the decision is of the other teams of the same ideal point.

A.3 Equilibria in Decentralized

Suppose teams are allowed to make treaties, treaties are bilateral, and a treaty is composed of team i requesting a geoengineering production of g_{ij}^R from team j for a transfer of T_{ij} from team i to j, $i \neq j$. Proposed treaties are common knowledge, and team j accepts a treaty by producing as requested. Transfers from team i to team j happens when treaties are fulfilled, i.e., if more than one treaty is fulfilled, more than one transfer happens.

The proof will be in 4 stages. First, we will show the equilibria under $N = 2$. And then, we will show that under $N = 3$, any global production higher than the second highest ideal production level is not an equilibrium. We will then show what happens if teams request similar production levels for similar or different amounts of transfer. Finally, using our results for $N = 2$ and $N = 3$, we generalize our proof $\forall N \geq 3$.

STEP1. Equilibria in *N*=2. Suppose there are two teams, 1 and 2, and $G_1^* < G_2^*$. In the absence of treaties, team 2 will produce $g_2 = G_2^*$ and team 1 will produce $g_1 = 0$ (i.e., the Baseline equilibrium). With treaties, team 1 can now make a treaty with team 2 to decrease its level of production from G_2^* to $g_{12}^R < G_2^*$ for a transfer of T_{12}. This implies that since team 2 has control over production under the Baseline, it has the production property rights and as such, transfers are made to it instead of the other way around. If team 2 accepts team 1's offer, the respective payoff functions of teams 1 and 2 will be:

$$\pi_1 = E - T_{12} - \lambda|g_{12}^R - G_1^*| \tag{A.2}$$

$$\pi_2 = E - \alpha g_{12}^R + T_{12} - \lambda|g_{12}^R - G_2^*| \tag{A.3}$$

However, if team 2 rejects team 1's offer to produce at its ideal level, the respective payoff functions of teams 1 and 2 will be:

$$\pi_1 = E - \lambda|G_2^* - G_1^*| \tag{A.4}$$

$$\pi_2 = E - \alpha G_2^* \tag{A.5}$$

Hence, from equations A.3 and A.5, team 2 will only accept team 1's offer iff:

$$E - \alpha g_{12}^R + T_{12} - \lambda|g_{12}^R - G_2^*| \geq E - \alpha G_2^*$$

$$T_{12} \geq \lambda|G_2^* - g_{12}^R| - \alpha(G_2^* - g_{12}^R)$$

Since $G_2^* > g_{12}^R$ by definition, the equation above can be rewritten as:

$$T_{12} \geq (\lambda - \alpha)(G_2^* - g_{12}^R) \tag{A.6}$$

On the other hand, from equations A.2 and A.4, team 1 will only make an offer iff

$$E - T_{12} - \lambda|g_{12}^R - G_1^*| \geq E - \lambda|G_2^* - G_1^*|,$$

which can also be rewritten as

$$T_{12} \leq \lambda(G_2^* - G_1^* - g_{12}^R + G_1^*)$$

$$T_{12} \leq \lambda(G_2^* - g_{12}^R) \tag{A.7}$$

What treaty should team 1 offer to team 2? Team 1 should make an offer, (T_{12}, g_{12}^R), that maximizes $\pi_1(T_{12}, g_{12}^R)$ while, at the same time, fulfilling conditions A.6 and A.7. Since $\max\{E - T_{12} - \lambda|g_{12}^R - G_1^*|\} = \min\{T_{12} + \lambda|g_{12}^R - G_1^*|\}$ and, for team 1, a unit decrease in global production is a gain of $\lambda > 1$ while a unit increase in transfers is a loss of 1, team 1 should minimize $\lambda|g_{12}^R - G_1^*|$ first and then, using condition A.6, figure out T_{12}. Moreover, minimizing T_{12} first implies a transfer of 0, which is the status quo. Hence, minimizing $\lambda|g_{12}^R - G_1^*|$ first yields the following results:

$$\begin{aligned} g_{12}^R &= G_1^* \\ T_{12} &= (\lambda - \alpha)(G_2^* - G_1^*) \end{aligned} \tag{A.8}$$

STEP2. Global Production under *N=3*. Suppose there are three teams — 1, 2, and 3 — and $G_1^* < G_2^* < G_3^*$. In the absence of treaties, team 3 will produce $g_3 = G_3^*$ and teams 1 and 2 will produce at $g_1 = g_2 = 0$ (i.e., the Baseline equilibrium). With treaties, team 1 can make a treaty with team 3 to decrease their level of production from G_3^* to g_{13}^R for a transfer of T_{13} and team 2 can make a treaty with team 3 to decrease their level of production from G_3^* to g_{23}^R for a transfer of T_{23}. Again, this implies that since team 3 has control over production under the Baseline, he has the production property rights and as such, transfers are made to him instead of the other way around. It is also worth noting that while team 1 can also make transfers to team 2 and the other way around, doing so is not efficient as neither of the teams are producing anything. Hence, we restrict treaties between non-producing teams in the Baseline and transfers from the team with the highest ideal point.

Proposition. Given $N = 3$, $G_1^* < G_2^* < G_3^*$, the possibility of making treaties, any G lower or higher than G_2^* is not an equilibrium.

Proof by Contradiction.

1. Suppose $G_1^* \leq G < G_2^*$. The profits for teams 1, 2, and 3 under a treaty that gives this level of global production are:

$$\begin{aligned} \pi_1 &= E - \alpha g_1 - T_{13} - \lambda|G_1^* - G| \\ \pi_2 &= E - \alpha g_2 - T_{23} - \lambda|G_2^* - G| \\ \pi_3 &= E - \alpha g_3 + T_{13} + T_{23} - \lambda|G_3^* - G|. \end{aligned}$$

   But what if team 2 increases its geoengineering production so that $G = G_2^*$? The new profit functions for teams 1, 2 and 3 are:

$$\begin{aligned} \pi_1' &= E - \alpha g_1 - T_{13} - \lambda|G_1^* - G_2^*| \\ \pi_2' &= E - \alpha(g_2 + G_2^* - G) - T_{23} - \lambda|G_2^* - G_2^*| \\ \pi_3' &= E - \alpha g_3 + T_{13} + T_{23} + T_{13}' + T_{23}' - \lambda|G_3^* - G_2^*|. \end{aligned}$$

   Because $G < G_2^*$, $\pi_3 < \pi_3'$. Hence, team 3 prefers the new deal over the old deal. Also, since $\alpha < \lambda$, team 2's incurred cost from production is offset by the gain from being closer to its ideal point. Moreover, knowing that team 2 will increase its geoengineering production if it expects production to be lower than its ideal point, team 1 is better off not making transfers, i.e, $T_{13} = 0$. Hence, $G_1^* \notin [G_1^*, G_2^*)$.

2. Suppose $G_3^* > G > G_2^*$. The profits for teams 1, 2, and 3 under a treaty that gives this

level of global production are:

$$\begin{aligned}
\pi_1 =& E - \alpha g_1 - T_{13} - \lambda(G - G_1^*) \\
\pi_2 =& E - \alpha g_2 - T_{23} - \lambda(G - G_2^*) \\
\pi_3 =& E - \alpha g_3 + T_{13} + T_{23} - \lambda(G_3^* - G).
\end{aligned}$$

But what if instead of offering treaties to team 3 to bring production level down to $G_3^* > G > G_2^*$, team 1 and/or 2 offer treaties to bring geoengineering down to $G = G_2^*$? This will yield the following profits:

$$\begin{aligned}
\pi_1' =& E - \alpha g_1 - T_{13} - T_{13}' - \lambda(G_2^* - G_1^*) \\
\pi_2' =& E - \alpha g_2 - T_{23} - T_{23}' - \lambda(G_2^* - G_2^*) \\
\pi_3' =& E - \alpha g_3 + T_{13} + T_{23} + T_{13}' + T_{23}' - \lambda(G_3^* - G_2^*).
\end{aligned}$$

As long as $T_{13}' + T_{23}' \geq \lambda(G - G_2^*)$, team 3 will accept the deal ($\pi_3' \geq \pi_3$). Is team 2 better off with this deal? Yes, because, as in STEP1, team 2 maximizes profits by minimizing costs, which is done by requesting for a production as close as possible to G_2^*. Is team 1 better off with this deal? Using the same line of reasoning as team 2, yes. Team 1 will want global production to be as close as possible to G_1^* and the global production of the new deal is closer to G_1^* than that of the old deal. Hence, $G \not> G_2^*$.

STEP3. Transfers under *N*=3. Given the assumptions and the results above, if $g_{13}^R \neq g_{23}^R$ and $G = G_2^*$. What happens if $g_{13}^R = g_{23}^R$? From Steps 1 and 2, $g_{13}^R = g_{23}^R = G_2^*$. Since there are two teams making an offer for the same production level, the total transfers for team 3 need to be $T_{13} + T_{23} \geq (\lambda - \alpha)(G_3^* - G_2^*)$ for team 3 to accept it. This implies that when teams 1 and 2 request for the same equilibrium production amount, this request can be supported by a smaller team transfer compared to when only one team is requesting the same production amount. Can a team free-ride on transfers offered by someone else? Yes. Will it free-ride? No. There is an incentive for a single team to engage in a treaty, regardless of the what the other team decides to do.

STEP4. Equilibria under $N \geq 2$. Now suppose there are N teams ($i \in N$) and that $G_1^* < G_2^* < ... < G_n^*$. Without treaties, $G = G_n^*$ where team n produces everything and all other teams produce nothing. Hence, as in the case of $N = 3$ (STEP2), with treaties, team n has property rights and production requests and transfers are made to team n by teams with ideal points lower than G_n^*. It is worth noting that treaties are bilateral agreements. Hence, for any n, the conditions required for any team to make and accept offers are similar to those in the case where $N = 2$ (STEP1). Moreover, recursively doing STEP2 for teams n and any other two teams, we find that $G = G_{n-1}^*$. As in STEP3, the total amount of transfers to team n should be greater than or equal to $(\lambda - \alpha)(G_n^* - G_{n-1}^*)$.

A.4 Equilibria in Treaty

The proof for Treaty is the same as that of Decentralized. In our experiment, we restrict team n from making transfers to any other team. We also only allow treaties to be made between team i, $i = 1, \ldots, n-1$ and team n. This should not change the above results. For simplification, a team i can only make 4 types of treaties which is composed of a combination between one of two g_{in}^R and one of two T_{in}. The two choices for T_{in} are low enough that at least two countries need to offer treaties for the same g_{in}^R for a treaty to be acceptable to team n.

B Instructions, quiz, questionnaire (translated from Italian)

B.1 Experimental instructions

INSTRUCTIONS

— *All sessions* —

Welcome, this is a study in economic decision-making funded by the European Commission. You will earn money depending on the decisions you and other participants make in today's session. Your earnings will be expressed in tokens and can vary depending on your decisions. For every 2 tokens you will earn during this session, you will receive 1 euro cent. At the end of this session, you will receive the the amount you earned throughout the session plus a show-up fee of 8 euros. You will be paid in private.

Unless you are asked to, please do not to communicate with other participants or look at their screens. Please turn off your cellphone. If you have any questions, you can raise your hand and somebody will come to you and answer your question in private.

Today's session will be composed of three parts. We will now read the instructions for the first part.

Part 1 instructions

— *All sessions* —

You will be matched with another person selected at random to form a team of two. You will remain in this team for today's entire session. You and your team mate will have identical earnings. You will be able to chat through your computer with your team mate, but you will not be able to communicate with the other team.

Your team will be matched with another team in the room. Your teams will be interacting for 5 rounds.

How are earnings generated?

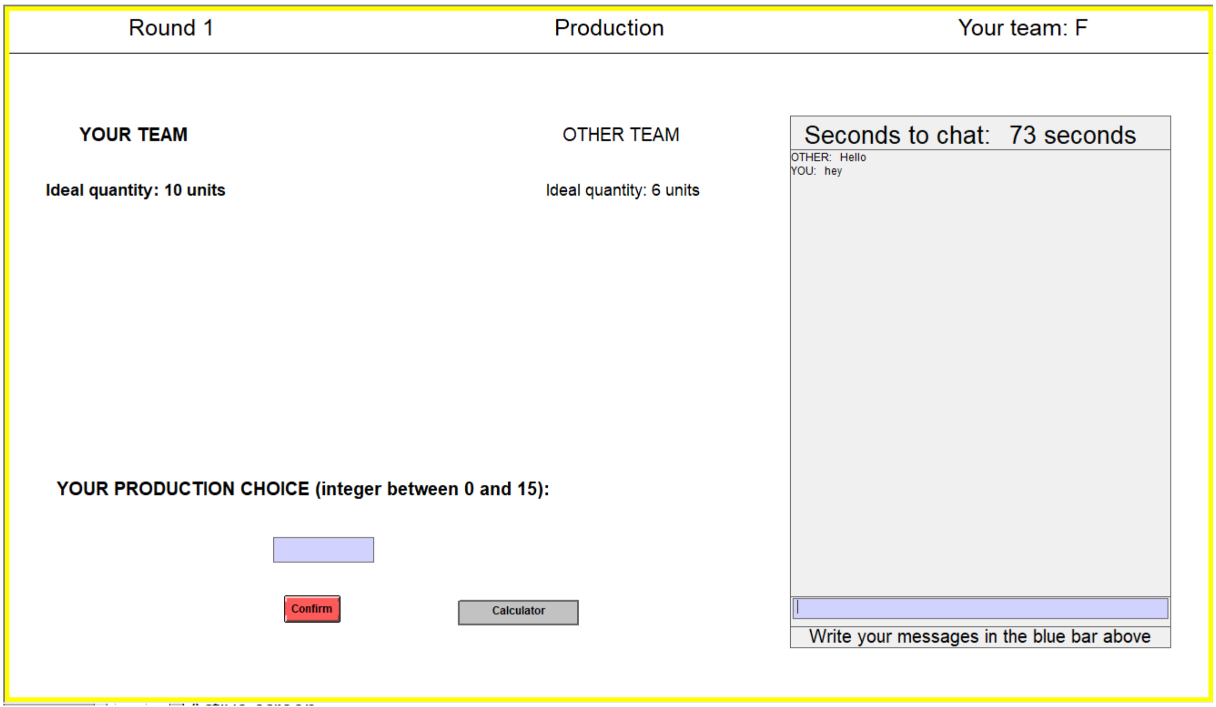
In every round each team will receive an **endowment** of 150 tokens and must decide how much of it to use during the **production** stage. Each team has an ideal quantity in terms of total production, which can be 2, 6, or 10 units (always in terms of total production). Total production is simply the sum of productions of the two teams. The closer total production is to your team's ideal quantity, the more you earn. The ideal quantities of the two teams will be displayed on your computer screen.

Example:

Suppose your team's ideal quantity is 10 units. If you produce 10 units and the other team produces 2 units, total production will be 12 units. Hence, your team is better off decreasing its production from 10 to 8 units, in order to reach a total production of 10 units. What damages your team is both an insufficient production and an excessive production.

Let's be more precise.

The figure below illustrates the screen for the production stage. Your production must be an integer number between 0 and 15 units. Entering anything other than an integer will be counted as a production of 0 units. Each token that you leave in your endowment generates 1 token in earnings and each unit you produce costs 4 tokens that will be deducted from your endowment.



Your earnings are maximal when the total production is equal to your team's ideal quantity. If that's not the case, your earnings decrease by 10 tokens for every unit of distance between the total production and your team's ideal quantity. The damage is the same for an insufficient or excessive total production.

In summary, your earnings in a round are:

$$Your\ earnings = (150 - 4 \times Production) - 10 \times (Distance\ between\ total\ production\ and\ ideal\ quantity)$$

Example:

Continuing the example from the previous page where your ideal quantity is 10 units: if you produced 8 units and the other team 2 units. Your earnings are equal to:

$$= (Endowment\ of\ 150 - 4 \times Your\ production\ of\ 8\ units) - 10 \times (total\ production\ of\ 10\ units - ideal\ quantity\ of\ 10\ units)$$

$$= 118 \qquad\qquad - 0 = 118\ tokens$$

How do your earnings change if your team reduces its production to 7 units and the other team keeps a production of 2 units?

$$= 122 \qquad\qquad - 10 = 112\ tokens$$

You save 4 tokens on the production cost, but you suffer an additional damage of 10 tokens because now the total production is equal to 9, that is one unit less than your ideal quantity. Overall, your earnings reduces by 6 tokens.

Are there any questions?

We ask you to answer some review questions to make sure the instructions are clear. Please look at your screen.

To help you making decisions, you will have access to a calculator. To open the calculator please click on the calculator button on the lower side of your screen as shown in the figure above.

Can I chat with my team mate?

Before every decision, you will have a chance to communicate with the other person in your team via chat. To see how this works, look at your computer screen and enter a message in the blue bar on your right. Please type "hello" now followed by the Enter key to send the message.

Every round you will have up to 2 minutes to chat before deciding on production.

The chat is intended for you and your team mate to discuss what production level to choose. We encourage you to agree on a common decision as a team. In sending messages, you should follow two basic rules: (1) be civil to one another and do not use profanities, and (2) do not identify yourself in any manner. Your messages will be recorded and saved.

Every participant is asked to input a choice for the team. You and your team mate should enter the same choice. If there is disagreement on choices, you will both have the opportunity to re-enter a choice. If the disagreement persists, one of the two choices will be selected by a flip of a coin and will be treated as the team's final decision for the round.

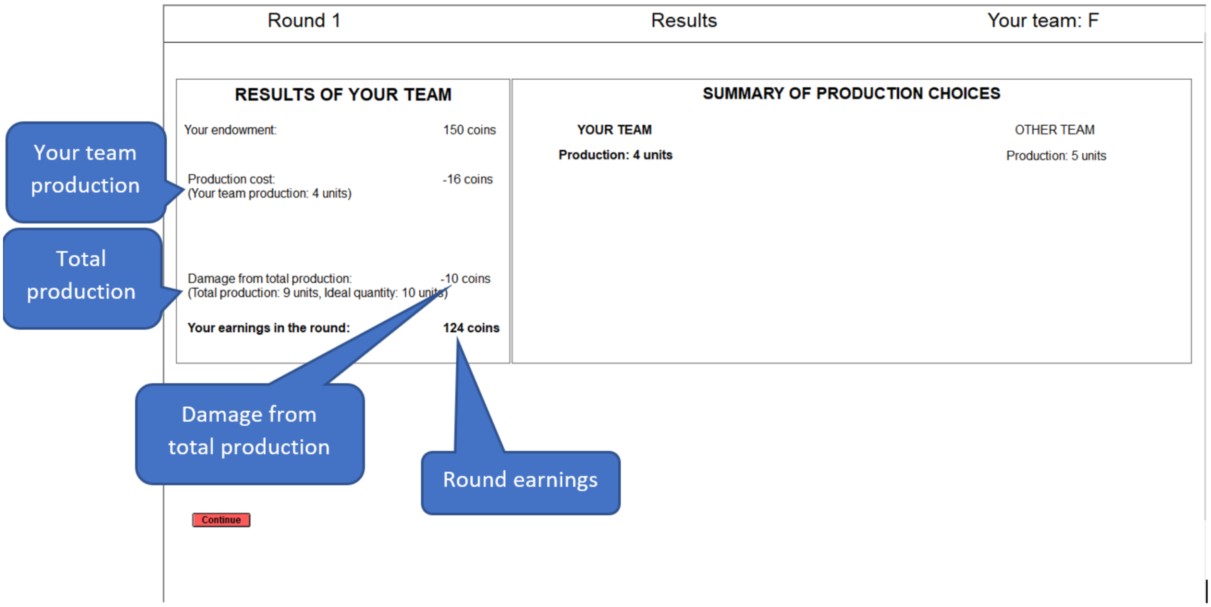
To sum up, the timeline in every round is as follow:

1. You receive an endowment
2. Chat with the other member of your team about production
3. Production decision
4. Results for the round

At the end of each round, you will be able to see the **results**. As shown below, the screen will display your team's production, total production, the damage from total production, and your team's earnings in the round.

The screen will show also the production decisions of the other team.

Subsequent rounds of part 1 will be identical to the initial one. Your ideal quantity will also remain the same. You will be paid the cumulative earnings across all rounds. A possible loss in a round will be compensated by earnings in the other rounds. We ask you to write the results of each round on the attached results sheet under the appropriate headings.



Are there any questions?

Before we get started, we ask you to answer some other review questions to check whether instructions were clear. Please, look at your screen.

Part 2 instructions

— Baseline sessions —

Your team and your team's ideal quantity remains the same.

You will interact with the same other team as in part 1 for **5 more** rounds.

In this part, you will only have one minute to use the chat.

Are there any questions?

— Decentralized sessions —

Your team and your team's ideal quantity remains the same.

You will interact with the same other team as in part 1 for **5 more** rounds but the rules of the interactions will now be different.

Every round includes an **initial promise stage** and a **subsequent production stage**. The production stage remains the same as in the first part.

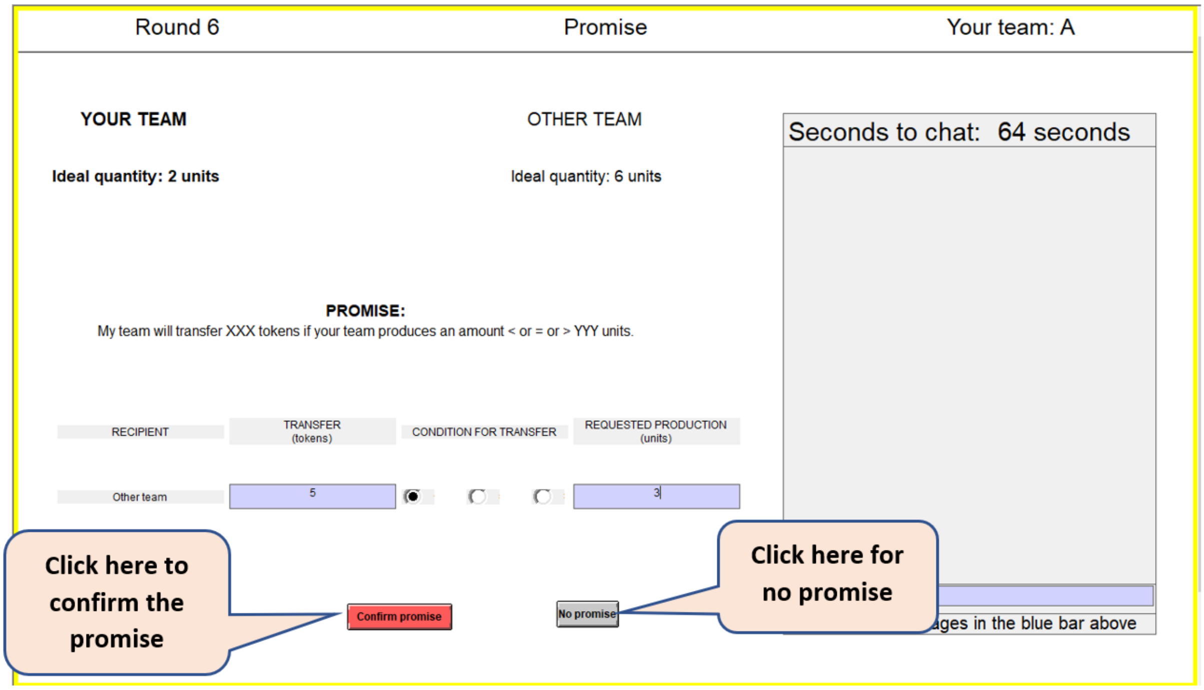
In this part, you will be able to promise a token transfer to another team. The transfer will only take place if the quantity produced by the other team fulfills your requests. That is, you can specify before that the transfer will take place when the production of the other team is lower, higher, or equal to a certain amount. Obviously, a team can abstain from making promises.

How to make promises?

Before the production stage, your team can make a unilateral promise to transfer to the other team an amount between 1 and 150 tokens. You can make the transfer conditional on any level of production of the other team between 0 and 15 units.

If your team is unwilling to make one, your team can proceed to the production stage.

The figure below shows how this can be done. To skip to the production stage you and your team mate can click on the button "no promise".



To make a promise, you and your team mate will be asked to specify the amount your team wants to transfer and under which condition ($>$, $<$, or $=$) in reference to the other team's production. Once you and your team mate have decided, click the button "Confirm". Once the promise has been made, it cannot be taken back: it will automatically be implemented at the end of the round if the production of the other team satisfies the request made by your team.

Example:

Suppose your team promises "20 tokens if the other team produces less than 3 units". If the other team produces 1 unit, 20 tokens will be subtracted from your team and the same amount will be added to the other team. If instead the other team produces 5 units, no transfer will happen.

When choosing the amount that your team wants to transfer, you and your team mate can put yourselves in the shoes of the other team to understand if the promised amount is sufficient to induce them to modify their behavior.

The screen will show a summary of both made and received promises, to help you during the production stage.

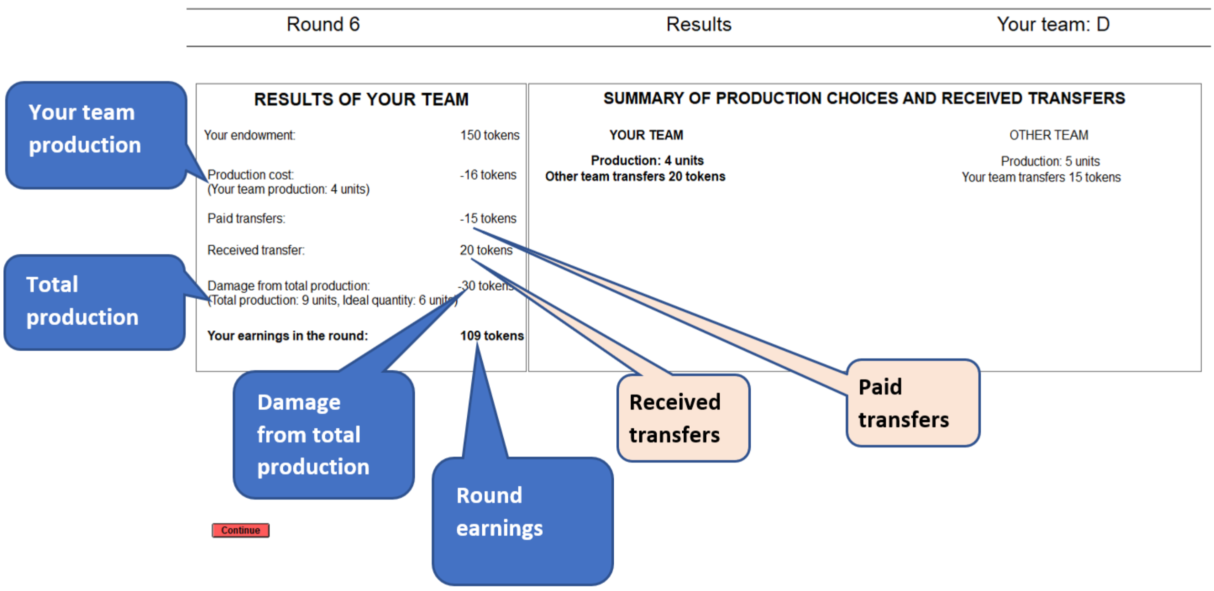
Are there any questions?

During each round you will have two minutes to chat before taking a decision concerning the promises and one minute before making the production decision.

To sum up, the timeline in every round is the following:

- You receive an endowment
- You can chat with your team mate about the promises
- Decision concerning the promise
- Received promises are shown
- You can chat with your team mate about the production
- Decision concerning the production
- Results for the round

At the end of each round, you will be able to see the results, which now also include the transfers that were actually received or paid by each team.



Basically, your earnings during each round will be:

$$
\begin{aligned}
Your\ earnings = (150 - 4 \times Your production) \\
-10 \times (Distance\ between\ total\ production\ and\ ideal\ quantity) \\
-Transfer\ paid\ to\ the\ other\ team+ \\
+Transfer\ received\ from\ the\ other\ team
\end{aligned}
$$

Are there any questions?

Before we start, we ask you to answer a few more questions to check if instructions were clear.

— *Treaty sessions* —

Your team and your team's ideal quantity remains the same.

You will interact with the same other team as in part 1 for **5 more** rounds but the rules of the interactions will now be different.

Every round includes an **initial promise stage** and a **subsequent production stage**. The production stage remains the same as in the first part.

In this part, some teams will be able to promise a token transfer to another team. The transfer will only take place if the quantity produced by the other team equals the requested amount. Obviously, a team can abstain from making promises.

Who can make promises?

Only some teams will have the possibility to make a promise. When two teams interact, the team with the lower ideal point will be able to make a promise. The other team can only receive the promise.

How to make promises?

Before the production stage, the team able to make a promise can transfer to the other team an amount of either 34 or 70 tokens, depending on the what is the choice of the team making the promise. The transfer is conditional on the level of production of the other team. The team making the promise of a transfer can choose to ask for a production equal to 6 or 2 units.

If your team is able to make a promise but unwilling to make one, your team can proceed to the production stage.

The figure below shows how this can be done. To skip to the production stage you and your team mate can click on the button "no promise".

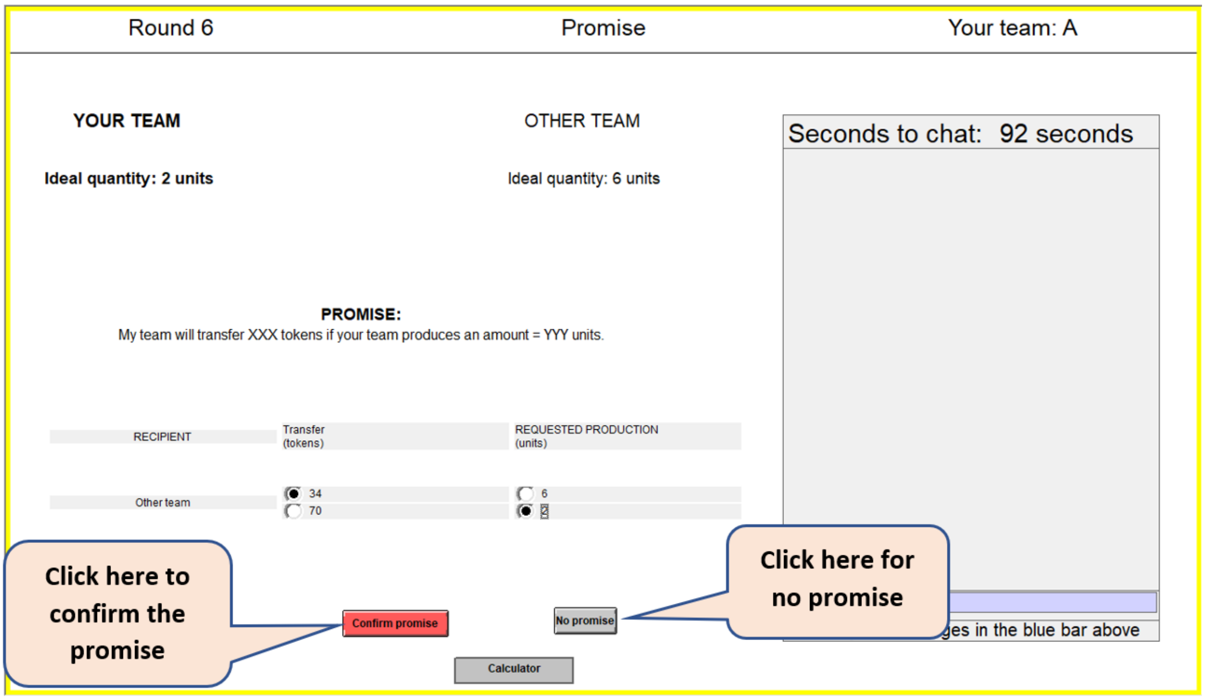
To make a promise, you and your team mate will be asked to specify the amount your team wants to transfer (34 or 70 tokens) and for which level of production the other team should produce (6 or 2 units). Once you and your team mate have decided, click the button "Confirm". Once the promise has been made, it cannot be taken back: it will automatically be implemented at the end of the round if the production of the other team satisfies the request made by your team.

Example:

Suppose your team promises "70 tokens if the other team produces 2 units". If the other team produces 2 units, 70 tokens will be subtracted from your team and the same amount will be added to the other team. If instead the other team produces 5 units, no transfer will happen.

When choosing the amount that your team wants to transfer, you and your team mate can put yourselves in the shoes of the other team to understand if the promised amount is sufficient to induce them to modify their behavior.

For instance, if the other team is solely responsible for total production and this is equal to



their ideal quantity, how much does the other team lose when total production is reduced to 4 units? On one hand, lowering production to 4 units allow a savings of $4 \times 4 = 16$ tokens on the production cost. On the other hand, moving total production away from the other team's ideal quantity, incurs the other team damages of $10 \times 4 = 40$ tokens. Hence, the other loses a total of $40 - 16 = 32$ tokens in earnings.

The screen will show a summary of both made and received promises, to help you during the production stage.

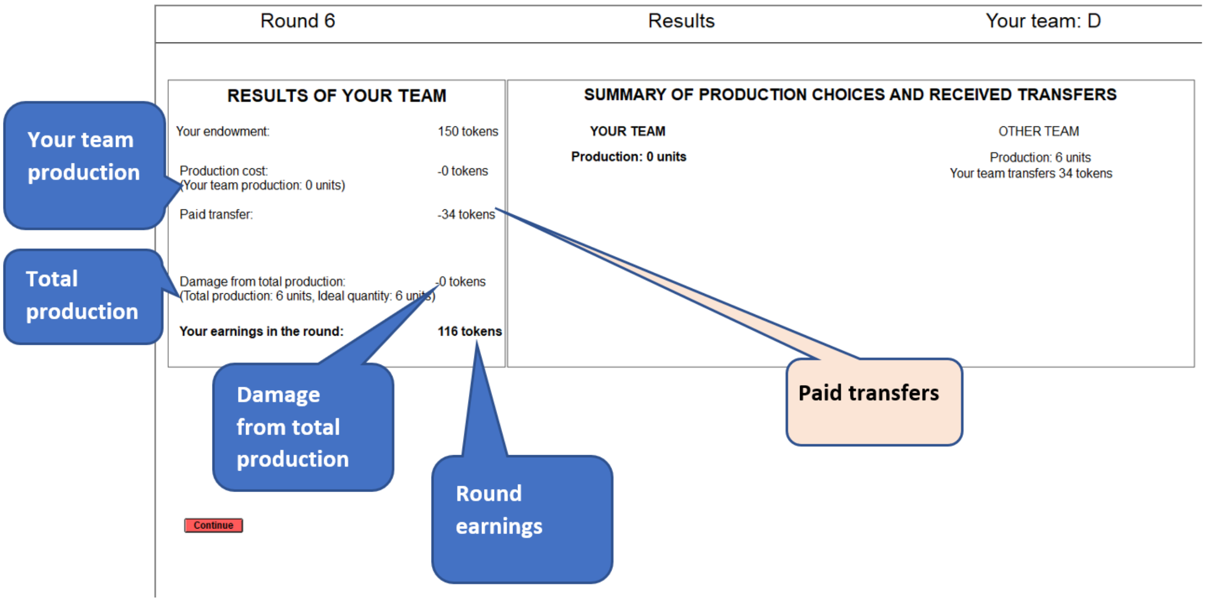
Are there any questions?

During each round you will have two minutes to chat before taking a decision concerning the promises and one minute before making the production decision.

To sum up, the timeline in every round is the following:

- You receive an endowment
- You can chat with your team mate about the promises (only if your team is allowed to make promises)
- Decision concerning the promise (only if your team is allowed to make promises)
- Received promises are shown
- You can chat with your team mate about the production
- Decision concerning the production
- Results for the round

At the end of each round, you will be able to see the results, which now also include the transfers that were actually received or paid by each team.



Basically, your earnings during each round will be:

$$
\begin{aligned}
Your\ earnings = (150 - 4 \times Your production) \\
-10 \times (Distance\ between\ total\ production\ and\ ideal\ quantity) \\
-Transfer\ paid\ to\ the\ other\ team + \\
+Transfer\ received\ from\ the\ other\ team
\end{aligned}
$$

Are there any questions?

Before we start, we ask you to answer a few more questions to check if instructions were clear.

Part 3 instructions

— *Baseline sessions* —

You will remain in the same team as before.

The rules for the interactions will be the same as before, but your team will now interact with **5 other teams** for **15 rounds**.

The ideal quantity of your team is the same as before, but you could find it useful to also know the ideal quantity of the other teams — because now the total production is the sum of the productions of all six teams. You will see the ideal quantities of the teams on your screen during the production stage as shown in the figure below:

Basically, two teams will have an ideal quantity of 2 units of production, two other teams will have an ideal quantity of 6 units of production, and the remaining two will have an ideal quantity of 10 units of production. In the upper-right corner of the screen you will see which is your team.

Are there any questions?

If you haven't done it already, remember to write on your results sheet today's date, the ideal quantity, and your team letter.

Before we start, we ask you to answer a few more questions to check if instructions were clear.

— *Decentralized sessions* —

You will remain in the same team as before.

The rules for the interactions will be the same as before, but your team will now interact with **5 other teams** for **15 rounds**.

The ideal quantity of your team is the same as before, but you could find it useful to also know the ideal quantity of the other teams — because now the total production is the sum of the productions of all six teams. You will see the ideal quantities of the teams on your screen during the production stage as shown in the figure below:

Basically, two teams will have an ideal quantity of 2 units of production, two other teams will have an ideal quantity of 6 units of production, and the remaining two will have an ideal quantity of 10 units of production. In the upper-right corner of the screen you will see which is your team.

Your team can make one promise in every round. Choose a team, decide the amount that you are willing to transfer, and the conditions for it. All promises made and received by each of the teams will be reported on the screen before the production stage.

Are there any questions?

If you haven't done it already, remember to write on your results sheet today's date, the ideal quantity, and your team letter.

Before we start, we ask you to answer a few more questions to check if instructions were clear.

— *Treaty sessions* —

You will remain in the same team as before.

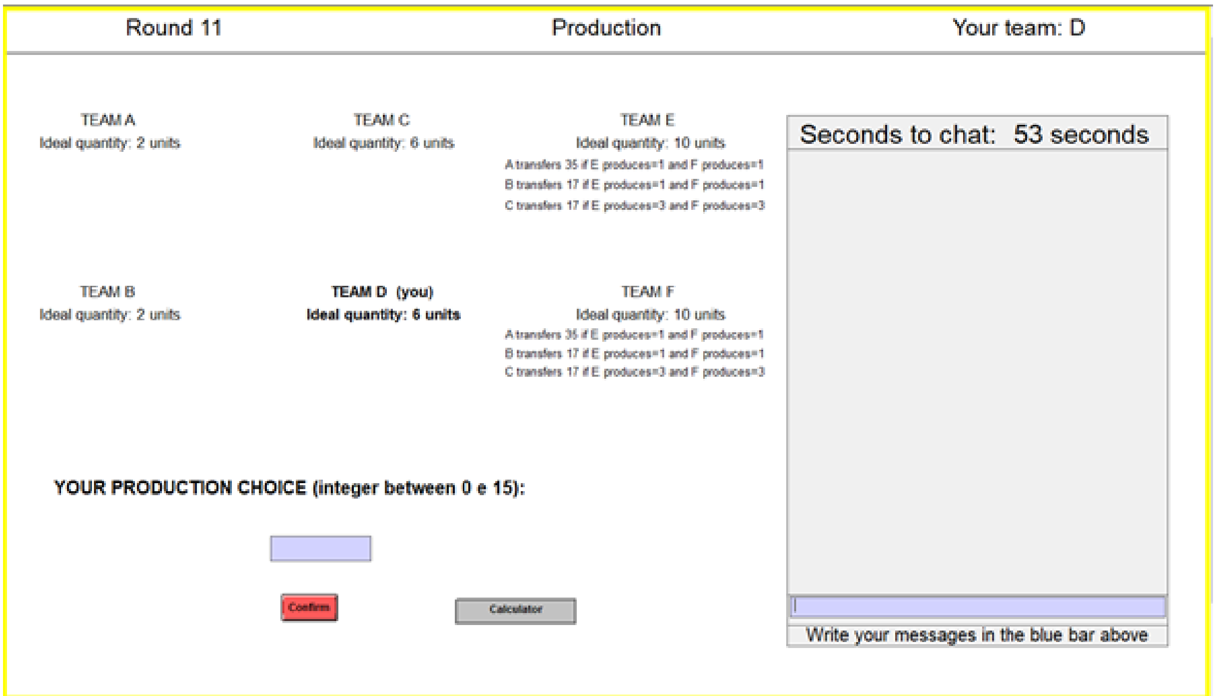
The rules for the interactions will be the same as before, but your team will now interact with **5 other teams** for **15 rounds**.

The ideal quantity of your team is the same as before, but you could find it useful to also know the ideal quantity of the other teams — because now the total production is the sum of the productions of all six teams. You will see the ideal quantities of the teams on your screen during the production stage as shown in the figure below:

Basically, two teams will have an ideal quantity of 2 units of production (teams A and B), two other teams will have an ideal quantity of 6 units of production (teams C and D), and the remaining two will have an ideal quantity of 10 units of production (teams E and F). In the upper-right corner of the screen you will see which is your team.

Some teams can make promises in every round. More precisely: each of the teams A, B, C, and D can make a promise towards teams E and F. Meanwhile, teams E and F cannot make promises but can only receive them.

As before, in order to make a promise, you and your team mate will be asked to specify which **amount you want to transfer** (34 or 70 tokens). Different than before, the **production level you select** (3 or 1 units) **simultaneously applies to team E and to team F**.



Example:

Suppose you promise to "transfer of 34 tokens if team E produces 3 units and team F produces 3 units". If both teams E and F produce 3 units each, your team will be subtracted 34 tokens. The amount transferred will be equally split: 17 tokens will be added to team E and 17 tokens will be added to team F. On the other hand, if team E produces 3 units while team F produces 5 units, no transfer will happen.

In the case in which more teams make promises for the same level of production, the transfer amounts add up. For example: if team A promises a "transfer of 34 tokens for a production of $3+3$" and team D does the same, this is equivalent to a promise of a "transfer 140 tokens for a production of $3+3$".

The screen will show a summary of the promises received by each team, to help you in the production stage. For example with the following received promises:

A transfers 35 if E produces=1 and F produces=1
C transfers 17 if E produces=3 and F produces=3
D transfers 35 if E produces=1 and F produces=1

Team E can receive 70 tokens (35 from A + 35 from D) if it produces 1 and, alternatively, can receive 17 tokens (from C) if it produces 3. This will happen only when also team F fulfills the request.

Are there any questions?

If you haven't done it already, remember to write on your results sheet today's date, the ideal quantity, and your team letter.

Before we start, we ask you to answer a few more questions to check if instructions were clear.

Date: ______ Ideal quantity: ______ Team: ______

Results sheet

Round	**Your team production** S	**Total production** T	**Damage from total production** =10—T-Ideal Q—	**Round earnings** =150-4S-Damage
1				
2				
3				
4				
...				
25				

B.2 Review questions

Part 1

— *All sessions* —

First set of questions:

1. How many participants are your team? 1 2 6 10
2. With how many other teams will your team interact? 0 1 2 5
3. Can I see the ideal quantity of the other team? Yes No
4. If your team uses 2 tokens for the production and the other team uses 9 tokens, how much is the total production? ______
5. Compute your round earnings = 150 tokens in your endowment — cost of 4 for each unit you produce — damage of 10 for each unit of distance between your ideal quantity and the total production. Consider the situation where your team produces 1 unit and the total production is 12; your ideal quantity is 2. ______

Second set of questions:

1. Can I use the chat to ask my team mate his/her name? Yes No
2. You can communicate only in the first round. Yes No
3. If my production choice differs from that of my team mate, will I have 0 earnings? Yes No
4. If my final production choice is 15 and that of my team mate is 7, which will be the final decision of the team? My choice The average 7 or 15 with equal chances

Part 2

— Transfer sessions —

1. You promised to transfer 19 tokens to the other team if it produces less than 7 units. Your team produces 6 units and the other team produces 8 units. Will you have to pay the transfer?
2. The other team promised to transfer 30 tokens to you if your team's production is equal to 5 units. You produce 4 units. Will you receive the transfer?

— Treaty sessions —

1. You promised to transfer LOW tokens to the other team if it produces LOW units. Your team produces 2 units and the other team produces 4 units. Will you have to pay the transfer?
2. The other team promised to transfer HIGH tokens to you if your team's production is equal to LOW units. You produce LOW units. Will you receive the transfer?

Part 3

— All sessions —

1. Suppose all teams, including yours, produce 2 units. What is the total production? _____
2. Suppose you produce 0 and every other team produces 3. What is the total production? _____
3. Suppose that the total production is 7 units. Who earns the least among the teams?
   Those with ideal quantity of 2 Those with ideal quantity of 6 Those with ideal quantity of 10

B.3 Final questionnaire

1. Please tell me, in general, how willing or unwilling you are to take risks? Please use a scale from 0 to 10, where 0 means "completely unwilling to take risks" and a 10 means you are "very willing to take risks".
2. Imagine the following situation: Today you unexpectedly received 1,000 Euro. How much of this amount would you donate to a good cause?
3. How willing are you to give to good causes without expecting anything in return?

   1 - unwilling to do so

   10 - very willing to do so
4. How well do the following statements describe you as a person: "If I am treated very unjustly, I will take revenge at the first occasion, even if there is a cost to do so."

1 - does not describe me

10 - describes me perfectly

5. How willing are you to punish someone who treats you unfairly, even if there may be costs for you?

   1 - unwilling to do so

   10 - very willing to do so

6. How willing are you to punish someone who treats others unfairly, even if there may be costs for you?

   1 - unwilling to do so

   10 - very willing to do so

7. How well do the following statements describe you as a person: ”When someone does me a favor I am willing to return it”

   1 - does not describe me

   10 - describes me perfectly

8. Please think about what you would do in the following situation. You are in an area you are not familiar with, and you realize you lost your way. You ask a stranger for directions. The stranger offers to take you to your destination. Helping you costs the stranger about 20 Euro in total. However, the stranger says he or she does not want any money from you. You have six presents with you. The cheapest present costs 5 Euro, the most expensive one costs 30 Euro. Do you give one of the presents to the stranger as a thank-you gift? If so, which present do you give to the stranger?

   (a.) No present

   (a.) Present value worth 5 Euro

   (a.) Present value worth 10 Euro

   (a.) Present value worth 15 Euro

   (a.) Present value worth 20 Euro

   (a.) Present value worth 25 Euro

   (a.) Present value worth 30 Euro

9. What is your field of study?

   (a.) Economics, business, finance

   (a.) Other social sciences, law

   (a.) Natural sciences, engineering, statistics, mathematics, medicine, etc.

   (a.) Literature, foreign languages, history, art, other humanities

10. How many economics studies similar to this one did you participated in before today?

    (a.) 1

    (a.) 2

    (a.) 3 or more

11. How do you evaluate the difficulty of this study?
    1 - Very easy
    4 - Very difficult
12. Do you regret any decision you made during this study? Why?

C Behavioral reactions to change in strategic environment

Participants seem to have a rather good undestanding of the strategic situation. We support this statement using two analyses on the experimental data. One focuses on economies of two under the Baseline rules (Parts 1 and 2), while the other on the switch between economies of two toward economies of six (Part 2 vs. 3). Using data from economies of two, we can compare teams' efforts with the same ideal point when belonging to different types of economies. For instance, M teams are expected to exert no effort when matched with H teams, while they are expected to exert effort equal to 6 when matched with L teams. Data tend to confirm this prediction, especially in Part 2.[3] In particular, M teams' average effort was 5.8 when matched with an L team and 0.8 when matched with an H team (Table C.1). The behavior of L and H teams was also quite in line with the prediction that they should exert an effort of 0 and 10, respectively, regardless of the economy type. Specifically, L teams' average efforts were 0.2 and 1.3 when matched with M and H teams, respectively, while H teams' average efforts were 8.6 and 8.2 when matched with L and M teams, respectively. Teams reacted according to predictions also when moving from bilateral (Part 2) to multilateral (Part 3) economies. On average, M teams matched with an L team in Part 2 reduced their effort from 5.8 to 0.3, which is very close to the predicted effort of 0 (Table C.1). Instead, average efforts dropped from 8.6 to 3.8 for H teams who belonged to (L, H) economies and from 8.2 to 4.7 in (M, H) economies for H teams who belonged to (L, H) economies. All in all, teams appear to have well-understood incentives in Baseline.

D Within-team disagreements

We investigate the frequencies of within-team disagreements that remained unresolved. That is, observations where the two team members submitted different promise or effort decisions and the computer had to randomly pick one of the two decisions to be implemented as the final team decision.[4] For each treatment, Figure D.1 reports the share of economies in a period

[3] We detect no significant differences in average efforts between Parts 1 and 2 in the Baseline treatment (Table F.4 in the Appendix).

[4] Team members had the opportunity to resolve an initial disagreement by reentering their decisions a second time. Team members were not allowed to communicate at this stage, but the software showed to each member the decision of the other member. An unresolved disagreement occurs when even after the second opportunity team members decisions differed. Concerning promises, team members could disagree in the promised side-payment, in the requested level of effort in both Decentralized and Treaty. In Decentralized team members could also disagree on the the sign and the target of the promise. Whenever we observe a difference in the team members decision in any of these elements, we count it as a disagreement.

Table C.1: Average teams' effort by economy type and part

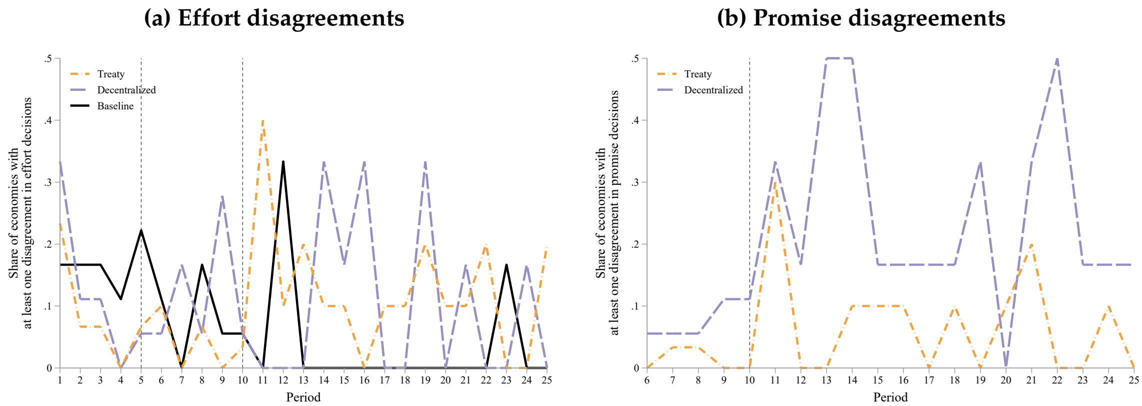
	Economy (L, M)		Economy (L, H)		Economy (M, H)	
	L	M	L	H	M	H
Baseline						
Part 1	0.800	5.000	1.167	8.300	1.567	7.567
	$\wr$	$\wedge\wedge\wedge$	$\wr$	$\wr$	$\wr$	$\wr$
Part 2	0.200	5.800	1.267	8.633	0.767	8.200
	$\wr$	$\vee\vee\vee$	$\wr$	$\vee\vee\vee$	$\wr$	$\vee\vee\vee$
Part 3	0.278	0.256	0.644	3.756	0.178	4.733
Decentralized						
Part 1	0.633	5.533	0.633	8.667	0.900	7.867
	$\wr$	$\wedge\wedge$	$\wr$	$\wr$	$\vee\vee$	$\wr$
Part 2	1.233	5.133	1.100	8.333	0.433	7.867
	$\wr$	$\vee\vee\vee$	$\vee$	$\vee\vee\vee$	$\vee$	$\vee\vee\vee$
Part 3	0.233	0.100	0.156	4.233	0.044	4.733
Treaty						
Part 1	0.520	5.200	1.080	8.420	1.380	8.000
	$\vee\vee$	$\vee\vee$	$\wr$	$\vee\vee$	$\vee\vee$	$\vee$
Part 2	0.080	3.700	0.820	7.020	0.640	6.720
	$\wedge$	$\vee\vee\vee$	$\wr$	$\vee\vee\vee$	$\wr$	$\vee\vee\vee$
Part 3	0.087	0.500	0.087	3.927	0.313	3.327

Notes: The unit of observation is the effort of a team in a round. $<$, $\ll$, and $\lll$ refer to $p < 0.1$, $p < 0.05$, and $p < 0.01$, respectively; p-values refer to linear regressions of the effort decision on dummy variables for Part 2 and Part 3 and controlling for random effects at team-level and a linear period trend with standard errors clustered at the economy-level (the economy is that in Part 3).

featuring at least one team whose members were unable to solve a disagreement. A first observation is that effort disagreements tend to be significantly more frequent in Decentralized and Treaty than in Baseline in part 3 ($p \leq 0.001$), but not so in parts 1 and 2 ($p \geq 0.206$).[5] A second observation is the absence of a clear trend across periods in effort disagreements in all treatments in parts 2 and 3 ($p \geq 0.317$). In part 1, a significant negative trend is estimated for Decentralized and Treaty ($p \leq 0.053$), but not for Baseline ($p = 0.846$). A third observation is that promise disagreements are more prevalent in Decentralized than in Treaty in both parts 2 and 3 ($p \leq 0.01$). Finally, we do not detect a significant correlation between the presence of disagreements in the economy and total earnings ($p \geq 0.208$).

[5] All p-values in this section come from linear regressions with random effects and clustered standard errors at economy-level.

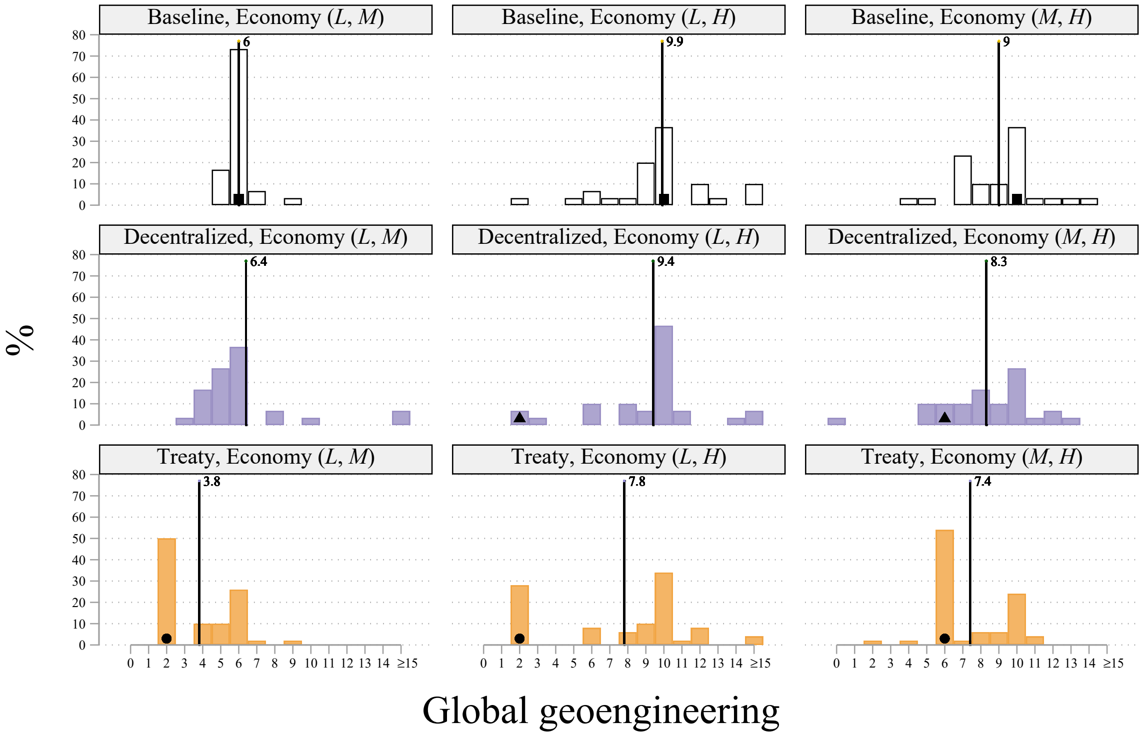
Figure D.1: Within-teams disagreements



Notes: An observation is one economy in a period. Dashed vertical lines mark the end of a part of the experiment.

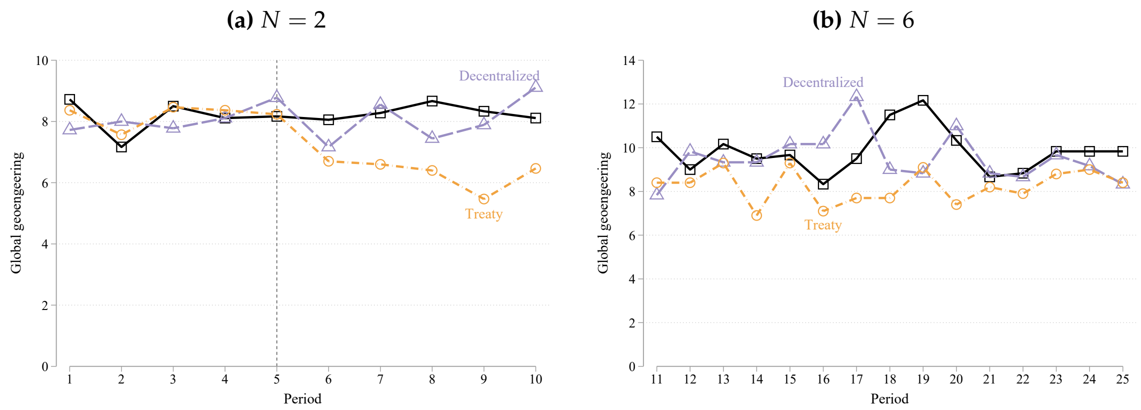
E Supplementary figures

Figure E.1: Global geoengineering in economies of two



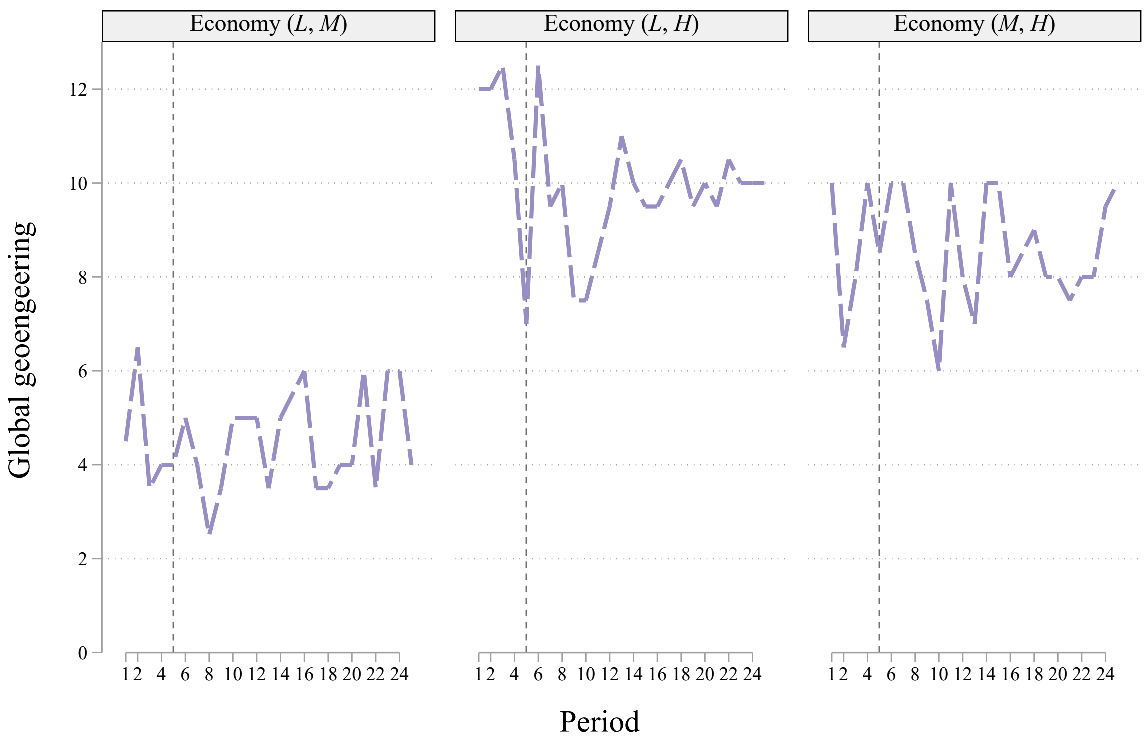
Notes: An observation is one economy in a period of Part 2. Solid symbols represent the SPNE predictions. Vertical lines highlight the average global geoengineering level.

Figure E.2: Evolution of global geoengineering



Notes: An observation is one economy in a period. The vertical line in panel (a) marks the last period of Part 1.

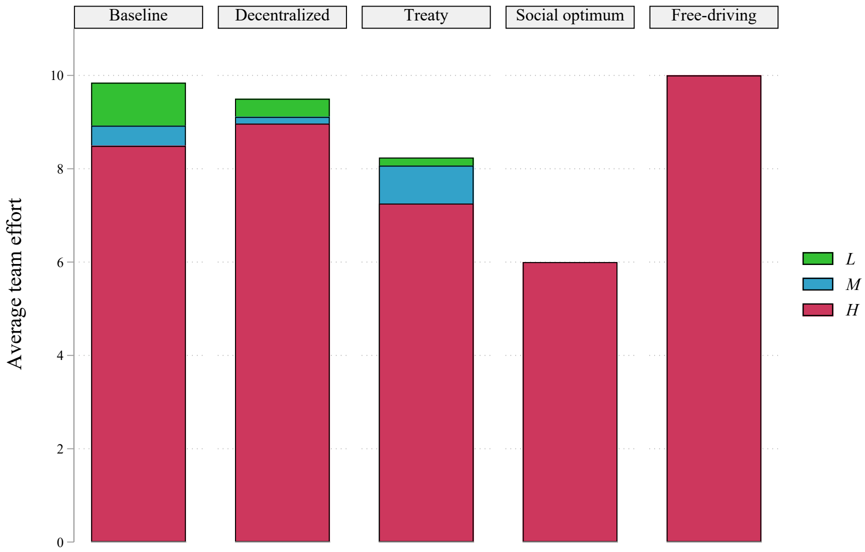
Figure E.3: Evolution of global geoengineering in Decentralized with $N = 2$–Robustness



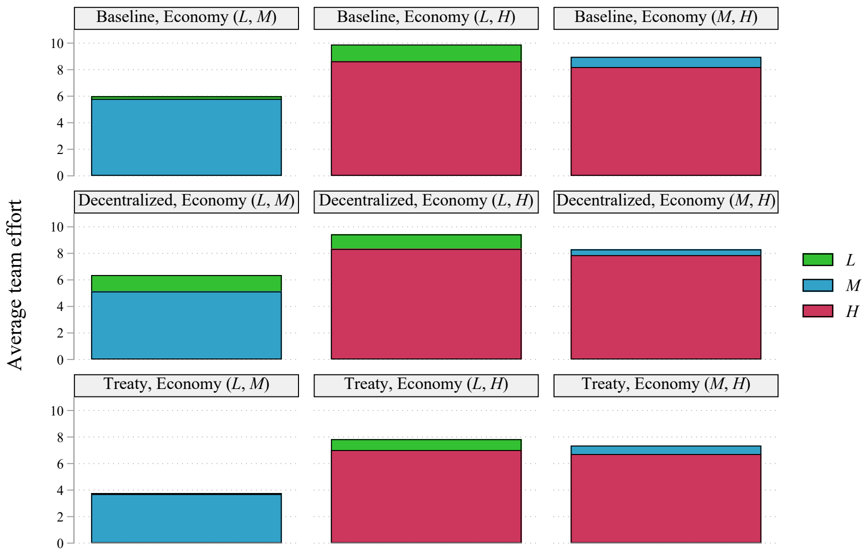
Notes: Data from a robustness check session of Decentralized where teams played in economies of two throughout the whole session. An observation is one economy in a period. The vertical lines mark the end of Part 1 (Baseline with $N = 2$) and the beginning of Part 2 (Decentralized with $N = 2$).

Figure E.4: Effort composition

(a) $N = 6$



(b) $N = 2$



Notes: An observation is one economy in a period of Part 3. The last two columns represent theoretical benchmarks common to all treatments.

F Supplementary tables

Table F.1: Effects of Decentralized and Treaty in economies of six

	(1) Global geoengineering	(2) Total surplus	(3) Gini index
Decentralized	-0.344 (0.427)	18.933 (19.631)	0.004 (0.008)
Treaty	-1.604 (0.576)***	51.720 (19.165)***	-0.010 (0.008)
Period number	-0.001 (0.036)	2.850 (1.206)**	
Constant	9.868 (0.815)***	535.093 (29.008)***	0.088 (0.006)***
Decentralized − Treaty	1.260 (0.480)***	-32.786 (15.729)**	0.014 (0.007)***
Observations	330	329	22
Economies	22	22	22

Notes: Estimates from linear regressions with clustered standard errors at the economy-level. At the bottom of the table results from Wald tests comparing Decentralized and Treaty are reported. An observation is one economy in a period of Part 3 in columns (1) and (2) and is an economy in the last period of Part 3 in column (3). Columns (1) and (2) include random effects at economy level.

Table F.2: Effects of Decentralized and Treaty in economies of two

	(1) Global geoengineering	(2) Total surplus	(3) Gini index
Decentralized	-0.056 (0.574)	1.778 (8.359)	-0.000 (0.012)
Treaty	0.067 (0.577)	-1.600 (8.143)	-0.005 (0.012)
Part 2	-0.094 (0.412)	-5.100 (6.835)	-0.000 (0.007)
Decentralized × Part 2	-0.200 (0.601)	-2.943 (8.860)	0.004 (0.009)
Treaty × Part 2	-2.029 (0.543)***	16.318 (6.079)***	0.000 (0.008)
Period number	0.050 (0.062)	0.540 (1.072)	
Constant	7.983 (0.486)***	203.846 (7.153)***	0.051 (0.009)***
Decentralized − Treaty in Part 2	1.829 (0.625)***	-19.262 (7.660)**	0.004 (0.006)
Observations	660	658	132
Economies	66	66	66

Notes: Estimates from linear regressions with clustered standard errors at the economy-level. At the bottom of the table results from Wald tests comparing Decentralized and Treaty are reported. An observation is one economy in a period of Parts 2 and 3 in columns (1) and (2) and is an economy in the last period of Parts 2 and 3 in column (3). Columns (1) and (2) include random effects at economy level.

Table F.3: Descriptive statistics and tests in parts 1 and 2, by economy type

	Baseline Mean (S.D.)	Decentralized Mean (S.D.)	p-value	Treaty Mean (S.D.)	p-value
Part 1					
Economy (L, M)					
Global geoengineering	5.800 (0.988)	6.167 (0.852)	0.419	5.720 (0.668)	0.825
Total surplus	226.133 (17.547)	226.000 (18.650)	0.873	229.520 (11.497)	0.913
Gini index	0.023 (0.022)	0.033 (0.020)	0.261	0.019 (0.014)	0.913
Observations	6	6		10	
Economy (L, H)					
Global geoengineering	9.467 (0.575)	9.300 (0.562)	0.687	9.500 (0.891)	0.870
Total surplus	173.467 (8.070)	178.133 (6.838)	0.199	170 (14.529)	0.828
Gini index	0.093 (0.036	0.083 (0.023)	0.522	0.087 (0.048)	0.745
Observations	6	6		10	
Economy (M, H)					
Global geoengineering	9.133 (1.178)	8.767 (0.814)	0.627	9.380 (1.368)	0.548
Total surplus	216.800 (13.194)	217.600 (7.350)	0.744	212.080 (18.373)	0.299
Gini index	0.037 (0.017)	0.036 (0.022)	0.873	0.032 (0.023)	1
Observations	6	6		10	
Part 2					
Economy (L, M)					
Global geoengineering	6.000 (0.179)	6.367 (2.092)	0.145	3.780 (1.291)	0.006
Total surplus	232.667 (5.931)	213.200 (45.359)	0.748	243.280 (8.470)	0.019
Gini index	0.025 (0.012)	0.042 (0.017)	0.109	0.023 (0.009)	0.914
Observations	6	6		10	
Economy (L, H)					
Global geoengineering	9.900 (2.349)	9.433 (2.285)	0.470	7.840 (2.941)	0.175
Total surplus	161.067 (27.189)	164.933 (31.359)	0.749	176.240 (29.857)	0.212
Gini index	0.094 (0.051)	0.082 (0.022)	0.200	0.102 (0.033)	0.745
Observations	6	6		10	
Economy (M, H)					
Global geoengineering	8.967 (1.183)	8.300 (1.367)	0.378	7.360 (1.391)	0.049
Total surplus	215.467 (13.705)	215.467 (8.385)	0.688	227.360 (8.810)	0.063
Gini index	0.034 (0.022)	0.040 (0.021)	0.749	0.014 (0.013)	0.104
Observations	6	6		10	

Note: $***\ p < 0.01$, $**\ p < 0.05$, $*\ p < 0.10$; p -values refer to Wilcoxon-Mann-Whitney exact tests of Baseline vs. Decentralized and Baseline vs. Treaty. The null hypothesis that the samples come from the same population. The unit of observation for Global geoengineering, and Total surplus is the average outcome in an economy in a part. Gini index is computed on cumulative earnings in the last round of each part.

Table F.4: Global geoengineering–Part 1 vs. Part 2

	Baseline			Decentralized			Treaty		
Economy	Part 1 Mean (S.D.)	p-value	Part 2 Mean (S.D.)	Part 1 Mean (S.D.)	p-value	Part 2 Mean (S.D.)	Part 1 Mean (S.D.)	p-value	Part 2 Mean (S.D.)
(L, M)	5.800 (0.988)	0.528	6.000 (0.179)	6.167 (0.852)	0.600	6.367 (2.092)	5.720 (0.668)	0.008	3.780 (1.291)
(L, H)	9.467 (0.575)	0.344	9.900 (2.349)	9.300 (0.562)	0.345	9.433 (2.285)	9.500 (0.891)	0.114	7.840 (2.941)
(M, H)	9.133 (1.178)	0.400	8.967 (1.183)	8.767 (0.814)	0.345	8.300 (1.367)	9.380 (1.368)	0.032	7.360 (1.391)
All	8.133 (1.922)	0.486	8.289 (2.229)	8.078 (1.577)	0.965	8.033 (2.252)	8.200 (2.037)	0.000	6.327 (2.683)

Note: $***\ p < 0.01$, $**\ p < 0.05$, $*\ p < 0.10$; p -values refer to Wilcoxon-Mann-Whitney exact tests of Baseline vs. Decentralized and Baseline vs. Treaty. The null hypothesis that the samples come from the same population. The unit of observation for Global geoengineering, and Total surplus is the average outcome in an economy in a part. Gini index is computed on cumulative earnings in the last round of each part.

G Robustness checks for bug in Treaty in Part 3

We study differences in outcome between Treaty sessions with a software bug in the layout of some periods in Part 3 versus Treaty sessions without bug. When focusing on our key economy-level outcomes, we observe small and statistically insignificantly differences between sessions with and without a bug (Table G.1). Similarly, the estimated treatment effects of Treaty on these key dimensions are not significantly different for sessions with and without the bug (Table G.2).

Table G.1: Descriptive statistics and tests in economies of six–Bug in Treaty

	Treaty without bug			Treaty with bug
	Mean	S.D.	p-value	Mean S.D.
Global geoengineering	8.013	(1.791)	0.675	8.467 (1.092)
Total surplus	633.547	(52.829)	0.917	631.733 (36.841)
Gini index	0.078	(0.021)	0.917	0.078 (0.016)
Observations	5			5

Note: p -values refer to Wilcoxon-Mann-Whitney exact tests of Treaty-OK vs. Treaty-BUG. The null hypothesis that the samples come from the same population. The unit of observation for Global geoengineering, and Total surplus is the average outcome in an economy in a part. Gini index is computed on cumulative earnings in the last round of each part.

Table G.2: Effects of Decentralized and Treaty in economies of six–Bug in Treaty

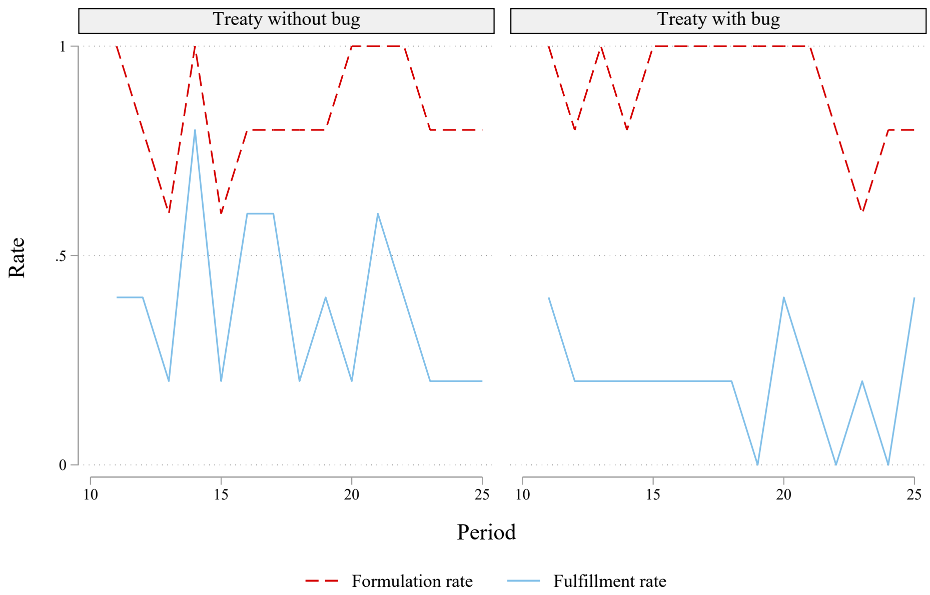
	(1) Global geoengineering	(2) Total surplus	(3) Gini index
Decentralized	-0.344 (0.427)	18.933 (19.631)	0.004 (0.008)
Treaty without bug	-1.831 (0.824)**	47.147 (26.843)*	-0.010 (0.011)
Treaty with bug	-1.378 (0.584)**	45.333 (21.914)**	-0.010 (0.009)
Period number	-0.001 (0.036)	3.784 (1.547)**	
Constant	9.868 (0.815)***	518.281 (33.828)***	0.088 (0.006)***
Treaty without − Treaty with bug	-0.453 (0.859)	1.813 (26.364)	0.000 (0.011)
Observations	330	330	22
Economies	22	22	22

Notes: Estimates from linear regressions with clustered standard errors at the economy-level. At the bottom of the table results from Wald tests comparing Treaty sessions with and without the bug are reported. An observation is one economy in a period of Part 3 in columns (1) and (2) and is an economy in the last period of Part 3 in column (3). Columns (1) and (2) include random effects at economy level.

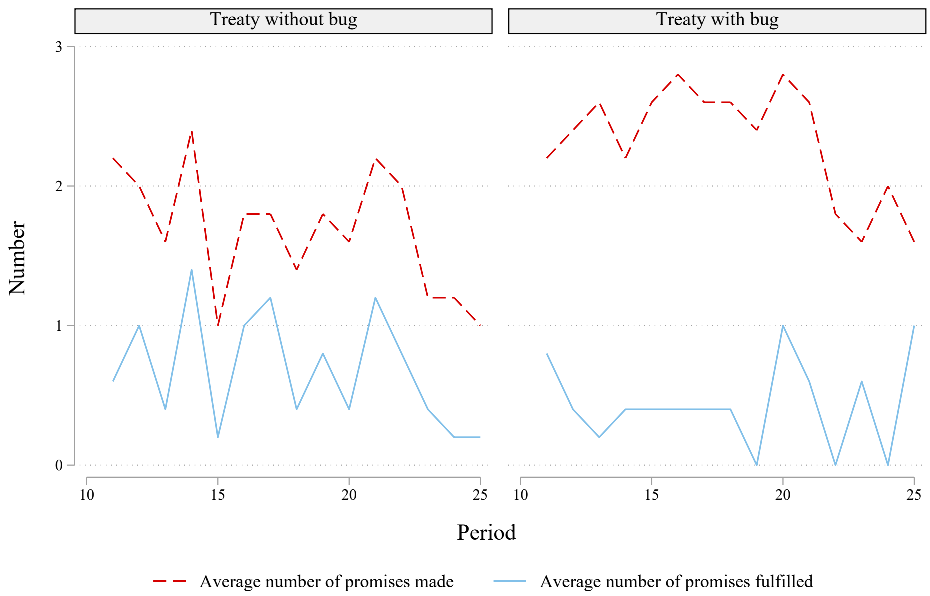
Finally, if we focus on promise patterns, we again fail to detect major differences in patters characterizing sessions with and without the bug. None of the differences in patterns depicted in Figure G.1 is statistically significant according to linear regressions with random effects and clustered standard errors at economy-level ($p \geq 0.182$).

Figure G.1: Promises' dynamics over periods–Bug in Treaty

(a) Promise formulation and fulfillment rates



(b) Average number of promises made to and fulfilled by high ideal point teams



Notes: An observation is one economy in a period.