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The climate commons dilemma: how can humanity solve the commons dilemma for the global climate commons?

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Abstract
In the era when human activities can fundamentally alter the planetary climate system, a stable climate is a global commons. However, the need to develop the economy to sustain the growing human population poses the Climate Commons Dilemma. Although citizens may need to support policies that forgo their country's economic growth, they may instead be motivated to grow their economy while freeriding on others' efforts to mitigate the ongoing climate change. To examine how to resolve the climate commons dilemma, we constructed a Climate Commons Game (CCG), an experimental analogue of the climate commons dilemma that embeds a simple model of the effects of economic activities on global temperature rise and its eventual adverse effects on the economy. The game includes multiple economic units, and each participant is tasked to manage one economic unit while keeping global temperature rise to a sustainable level. In two experiments, we show that people can manage the climate system and their economies better when they regarded the goal of environmentally sustainable economic growth as a singular global goal that all economic units collectively pursue rather than a goal to be achieved by each unit individually. In addition, beliefs that everyone shares the knowledge about the climate system help the group coordinate their economic activities better to mitigate global warming in the CCG. However, we also found that the resolution of the climate commons dilemma came at the cost of exacerbating inequality among the economic units in the current constrains of the CCG.

Keywords Climate change mitigation · Commons dilemma · Common knowledge · Sustainable development

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1 Introduction

Humanity now lives in the epoch that some call the Anthropocene, when human activities can fundamentally alter the workings of the Earth's biosphere (Crutzen 2002). In this context, a stable climate is a global public good (Kaul et al. 1999; Nordhaus 1994), and its sustenance requires a resolution of a commons dilemma (e.g., Dawes 1980; Hardin 1968). We call this the *climate commons dilemma* (CCD). Every country and every individual can enjoy a stable climate if it is sustained. However, as with any commons dilemma, there is a risk of freeriding—enjoying this public good without paying the cost for its provision. The catch is if all countries and citizens choose not to pay the cost, climate change is likely to continue unabated (Milinski et al. 2006; Milinski et al. 2008), and the long-term consequence is dire (IPCC 2014, 2018).

What complicates successful resolution of the CCD is the contemporary global circumstance for humanity. Climate change is ongoing, dangerously altering the planetary system (Rockström et al. 2009), while there is continuing global poverty—783 million people are living below the international poverty line of US$1.90 a day according to the United Nations (http://www.un-documents.net/our-common-future.pdf)—against the background of a growing human population (The United Nations 2019). The twin goals of sustaining the climate commons while eradicating poverty are highly resonant with the ideal of sustainable development (i.e., to maintain economic development while ensuring the environmental sustainability) (Brundtland 1987) and the UN's sustainable development goals. Indeed, climate-sustainable economic growth is fast becoming an imperative. This is because climate change has long-term economic costs (e.g., IPCC 2014; Nordhaus 2014; Stern 2007; Tol 2018), which are more likely borne by less wealthy segments of humanity, and this eventuality further exacerbates global inequality in wealth distribution (e.g., Hallegatte and Rozenberg 2017; IPCC 2014; Rao et al. 2017). Provided that inequality can undermine the collective effort to act on climate (Tavoni et al. 2011), rising global inequality can jeopardise sustainable development.

Therefore, countries and their citizens need to balance potential short-term costs of climate change policies and action against the long-term benefits of sustaining the planetary environment *and* human economic wellbeing (Nordhaus 1994, 2014) by containing global warming to 1.5–2 °C above the pre-industrial average (TheUnited Nations 2015a). Not only climate science but also social science approaches are necessary to address this pressing concern (IPCC 2014, 2018). The main objective of the present research is to investigate under what circumstances ordinary citizens can resolve the CCD by using a newly developed experimental paradigm, the *Climate Commons Game*, where economic growth is explicitly tied to changes in climate.

1.1 The behavioural science of the climate commons dilemma

Within a rapidly growing literature on the behavioural science of climate change (e.g. Clayton et al. 2015; Clayton et al. 2016), experimental approaches are often used to investigate people's ability to resolve the CCD via behavioural- or preference-based proxies for climate change action (Jacquet et al. 2013; Milinski et al. 2006; Milinski et al. 2008). In their groundbreaking work, Milinski et al. (2006) asked German university students how much they would contribute (€0, €1 or €2) to publish a newspaper advertisement about the importance of climate change mitigation. On average, a staggering 94.4% made a contribution when they were not anonymous and especially after reading an expert opinion about the significance of climate change, suggesting a general willingness to bear a personal cost to contribute to climate change action. Milinski et al. (2008) constructed another experimental paradigm, in which climate change mitigation was characterised as giving resources for a mitigation action to prevent the public “bad” of climate change. If the mitigation action is more likely to enable the participants to avoid the adverse effects of climate change, they are likely to contribute to mitigate climate change (for a review of studies using these paradigms, see Jacquet 2015).

The insights gained from these experiments have provided a valuable perspective on understanding ordinary citizens’ climate change action outside the lab (e.g., Aitken et al. 2011; Tam and Chan 2018), underscoring the utility of lab-based experimental approaches to understanding commons dilemmas (Falk and Heckman 2009; van Lange et al. 2013). However, existing experimental paradigms have two characteristics, which may limit insights about climate change action. First, the existing experimental paradigms concentrate on the CCD’s incentive structure, while largely bracketing out climate knowledge that is required to solve the CCD (Newell et al. 2014; Newell and Pitman 2010). Participants only need to understand that there is an action that, if taken, would successfully mitigate climate change. Details regarding what the action is or how that action would work to address climate change need not be considered. It follows that existing experimental tasks neglect the need for individuals (and societies) to address the cognitively complex task of balancing greenhouse gas (GHG) emissions and global warming against the costs and benefits of taking action on climate change (Burke et al. 2018; Burke et al. 2015; Nordhaus 2014).

Successfully stabilizing global climate requires taking action in a way that accounts for delayed feedback loops relating economic activities to global temperature increase, which in turn may adversely affect the economy itself (Nordhaus 2014; see Fig. 1). Although economic activities drive immediate changes in GHG emissions, their full effects on global warming take time to emerge, because of atmospheric GHG accumulation dynamics. Understanding such a human-climate system is evidently difficult. Even well-educated individuals have difficulty determining the level of emissions necessary to stabilise GHG concentration in the atmosphere (Moxnes and Saysel 2008; Sterman and Sweeney 2007) without additional cognitive support (Guy et al. 2013).

Sewell et al. (2017) constructed an experimental paradigm, which embeds a simplified human-climate system. Although its system dynamics are highly simplified, the task reflects the causal opacity of the nonlinear system dynamics with delayed effects (Fig. 1), which makes decision-making difficult. They found that it takes both an accurate mental model of the

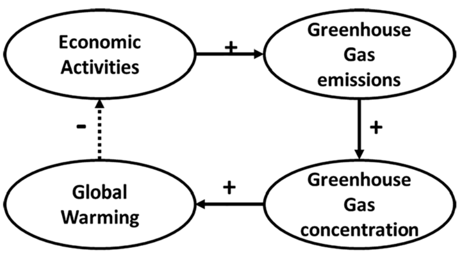

Fig. 1 A schematic causal structure of the economy and global warming. Economic activities produce green gas emissions, which accumulate in the atmosphere. Over time, the accumulated greenhouse gases produce global warming. Warming, in turn, has negative consequences for economic growth (e.g. by provoking changes in the viability of certain industries or creating instability). Because climate change mitigation entails reducing GHG emissions, within this framework, effective mitigation requires limiting economic activity

climate system and opportunity to learn about the feedback loop relating economic activities and global warming (i.e. the negative long-term effect of global warming on the economy) to sustainably manage economic activities.

Second, although existing paradigms highlight the importance of the CCD's incentive structure, they simplify its decision structure (i.e. how a decision to cooperate or freeride is *framed* within the game). In the existing paradigms (Milinski et al. 2006, 2008), participants are required to decide *how much to give* for climate change mitigation, which is called a give-some game, as opposed to a take-some game (Dawes 1980). However, when climate change is framed within the context of policymaking and policy preferences, climate action is often framed as *forgoing* the short-term benefit of economic growth and employment for the global public good. It is not giving but more akin to restraining oneself from taking more from the common resource pool. Given that decision framing of give-some vs. take-some often affects decision-making (e.g. Brewer and Kramer 1986; Rutte et al. 1987; van Dijk and Wilke 2000; van Dijk et al. 2003), insights from the existing CCD games may not generalise when the CCD is framed differently as characterised in Fig. 1.

1.2 Climate Commons Game

We extend Sewell et al. (2017) to construct our Climate Commons Game, an interactive task that emulates causal relationships between human economic activities, GHG emissions, and climate in a simplified way.

Participants play the role of the policy director of one of multiple economic units (analogous to a country's economy) in a dynamic environment in which economic activities are non-linearly linked to the climate, which in turn affect economic productivity. Their job is to set an economic growth target for each year to stimulate or restrict economic activities, so as to pursue a *sustainable development goal* (The United Nations 2015b; i.e., achieving long-term economic growth while keeping global warming at bay). For each economic unit, its economic performance is indicated by a numerical value, and the state of the global economy is indicated by the sum of all units' economic performances. The state of the climate system is indicated by the global temperature and the level of CO_2 concentration. In every round of the game, each economic director receives updated information about the global economy, the climate system and their own economic unit. Each director sets their own yearly economic target, chosen from a fixed range of positive and negative values (i.e. to accelerate or restrict economic growth). Each director's decision determines their unit's economic activities and GHG emissions, and all units' aggregated emissions determine the GHG concentration, global temperature (including delayed effects) and climate-affected economic outcomes (Fig. 1). This process continues for a set number of rounds.

The commons dilemma is inherent in this game. Each local economy can make a greater short-term gain by setting a higher growth target and rapidly growing their economy; however, in so doing, the aggregate GHG emissions increase, which in turn raises the atmospheric CO_2 concentration and therefore the global temperature. Higher temperatures adversely affect every country's economic productivity and therefore hamper its economic outlook in the long term. The decision structure for each economic director (i.e. participant) is homologous to that of a grazier that keeps adding cattle to the commons in Hardin's (1968) parable of the tragedy of the commons.

It may be argued that the director of an entire economic unit is an unrealistic arrangement for a participant. To be sure, an ordinary citizen, or for that matter, even the leader of a country, does not have this power. Nonetheless, in democratic processes, an ordinary citizen is ideally meant to consider the merits and drawbacks of policies if they are implemented and vote for those who advocate the policy that he or she decides is most suitable given the current circumstance. The game is designed to measure an individual's policy preference in this sense. By asking participants to make an economic decision as if they were the directors of the economic units, we can measure their preference for a level of economic growth that they believe would be most suitable given the economic and climate condition. Our question is therefore the following. When there is an incentive to grow the economy, but there is a great deal of causal opacity about the effects of their economic decisions on the climate system with delayed effects on their own economy, what circumstances would shape ordinary citizens' economic policy preferences if multiple economic units need to cooperate to keep the global temperature at a sustainable level? How can the climate change issue be communicated to support their policy preferences to resolve the CCD?

As noted by Pruitt and Kimmel (1977), to achieve cooperation, the multiple parties involved in a commons dilemma need to have a goal to achieve mutual cooperation and a mutual expectation that others will cooperate. What makes a commons dilemma difficult to solve is the requirement of mutuality. That is, only one party holding both the goal and expectation of mutual cooperation is insufficient; a majority, if not every party, needs to have both. In the CCG, the requirement of a mutually shared goal and expectation of cooperation is all the more difficult to meet because of the complex mental models required to balance economic and climate sustainability. In the present research, we investigate under what circumstances ordinary citizens have policy preferences that can resolve the CCD by manipulating the extent to which the goal of mutual cooperation is emphasised among the multiple economic units (experiments 1 and 2) and also the extent to which the expectation of mutual cooperation among the economic units is likely to be held (experiment 2). We discuss these factors in turn.

1.2.1 Goal of mutual cooperation

Although there are a number of factors that can create a goal of mutual cooperation among multiple parties (e.g., Pruitt 1967; van Lange et al. 1997), goal-framing is the most obvious. That is, if the parties involved in a commons dilemma all adopt a goal whose attainment requires or implies mutual cooperation, each party is likely to hold the subgoal of mutual cooperation. Indeed, it has been postulated and shown that when multiple groups share a superordinate goal whose achievement requires mutual cooperation among the groups, mutual cooperation is enhanced between groups while intergroup conflict is reduced (e.g., Gaertner et al. 2000; Sherif et al. 1961); more generally, cooperation goals tend to enhance group achievement and productivity (e.g., Johnson et al. 1981).

The Climate Commons Game has two overarching goals—growing the economy and keeping global temperature at bay. We factorially manipulated these goals in experiment 1. In the climate goal condition, the global temperature goal was explicitly set in line with the UN Paris Agreement, to keep the temperature rise within 2 °C above the pre-industrial average. In the no climate goal condition, this goal was not explicitly stated. We hypothesised the climate goal condition will help people manage the CCD.

H1. There should be greater cooperation in the Climate Commons Game (i.e. lower CO_2 concentration, and lower global temperature) in the climate goal condition than in the no climate goal condition.

The goal of economic growth can emphasise mutual cooperation or competition depending on how it is framed. On the one hand, economic growth is typically understood to be an individual economic unit's job. Each country is to grow its economy to ensure its citizens' wellbeing—well clad, well fed and well sheltered—and ensuring that they do not live in poverty. However, economic growth need not be construed as a purely local goal and can be viewed as a collective goal—to ensure that all humanity's needs are met as the human population increases. This is indeed reflected in the United Nation's Sustainable Development Goal (The United Nations 2015b). The Brundtland Report (Brundtland 1987) arguably frames the economic growth goal as a shared goal for all countries. We hypothesise that even if the same level of economic growth is set as a goal, the shared goal framing, relative to the individual goal framing, will help resolve the CCD.

H2. There should be greater cooperation in the Climate Commons Game in the shared goal framing than in the individual goal framing.

1.2.2 Expectation of mutual cooperation

The expectation of mutual cooperation is also important for cooperation, because most people are conditional co-operators (i.e., 'I will cooperate if you cooperate'; e.g., Fischbacher et al. 2001). Likewise in the CCD, expectations of others' cooperation are likely to be important. That accurate information about how the human-climate system works is *common knowledge* (Lewis 1969) or in *common ground* (Clark 1996; Clark and Brennan 1991) should facilitate people to coordinate their decisions. Having this information in common ground facilitates agreement on how to achieve sustainable development.

To make a case, we first need to clarify what common knowledge or common ground is. Lewis's (1969) definition of common knowledge is a strict logical requirement, and it can be paraphrased as follows. Information is common knowledge if everyone knows the information and also that everyone knows that everyone knows the information (and so on ad infinitum). (Clark 1996; Clark and Brennan 1991) made this requirement more psychologically plausible and suggested that information is in the common ground if everyone has a ground to believe that the information is true and also that everyone has a ground to believe that everyone believes that the information is true, and so on, to a reasonable cognitive limit.

In the CCD, that the human-climate system information is in common ground is particularly important. This is because one of the significant barriers to climate action may be a false belief that many people in their society are climate change sceptics (i.e. many people believe that climate change is not happening, or that even if it may be happening, it is not human caused). Leviston et al. (2012) found that citizens wildly overestimate the prevalence of climate change scepticism, and that those who (falsely) overestimate the prevalence of climate change scepticism tended to hold an entrenched climate change scepticism themselves. Given that climate change sceptics are less motivated to engage in climate change mitigation (e.g., O'Brien et al. 2018), false beliefs about the prevalence of climate change scepticism are likely to undermine people's beliefs about climate change mitigation, and are likely to undermine the belief that the human-climate system information is in common ground. We suggest that if participants do not believe that the human-climate system information is in common ground, they are unlikely to expect that others would be able to coordinate their economic activities with them.

A literature on commons dilemmas suggests the importance of common ground in achieving mutual trust and cooperation (van Dijk et al. 2009). Foddy et al. (2009) showed that people trusted others in their in-group only if their shared group membership (i.e. that they and those others all belonged to the same group) was in their common ground. Similarly, Thomas et al. (2014) found that sharing information about a commons dilemma situation in their common ground facilitated coordination. Facilitative effects of common ground were also detected in games where information about the game was passed on from one generation of players to the next generation (Chaudhuri et al. 2006; Chaudhuri et al. 2009). Field studies have also found that common pool resources can be cooperatively sustained if their users have a shared culture in their common ground (e.g. Ostrom 2015). Therefore, we hypothesise:

H3. There should be greater cooperation in the Climate Commons Game when the information about the human-climate system is in common ground than when it is not.

1.3 Present research

We investigate how goal-framing and common ground affect cooperation in the Climate Commons Game, the interactive decision-making task developed by Sewell et al. (2017), which emulates a dynamic human-climate system. The parameters governing the relationships between GHG emissions, atmospheric CO_2 concentration and temperature are based on the MAGICC intermediate earth complexity model (Meinshausen et al. 2011), providing an accurate depiction of the relevant dynamics. See Sewell et al. (2017) and Appendix C in the Electronic Supplementary for full details of the dynamics. The task simplifies the human-climate system but retains the essential features of the CCD and the causal opacity of the nonlinear system dynamics. Most importantly, it enables us to study the causal effects of goal framing and common ground on citizens' economic policy preference.

In experiment 1, we factorially manipulate the climate goal of keeping the temperature rise below 2 °C above the pre-industrial average (present vs. absent) and the framing of the goal of doubling the economy (collective vs. individual) in a four-person Climate Commons Game. In experiment 2, we set the goal of keeping the temperature rise below 2 °C for everyone but manipulate the framing of the economic goal (collective vs. individual) in a ten-person Climate Commons Game. We also examine the effect of expectation for mutual cooperation by manipulating whether the human-climate system information is in common ground.

2 Experiment 1

2.1 Materials and methods

2.1.1 Participants and procedure

A total of 600 US residents (150 groups of four, 55% male) were recruited from Amazon Mechanical Turk. Numbers of participants and groups in each condition are reported in Table 1. Those who agreed to participate were redirected to the online platform and read the plain language statement and consent form. Participants then completed the task and were debriefed and paid for their participation (US$3).

Table 1 Number of participants and groups in each condition in experiment 1 and experiment 2

Experiment 1				
	Individual economic goal		Shared economic goal	
	Climate goal absent	Climate goal present	Climate goal absent	Climate goal present
Number of participants	128	160	152	160
Number of groups	32	40	38	40
Experiment 2				
	Individual economic goal		Shared economic goal	
	Common ground	No common ground	Common Ground	No common ground
Number of participants	185	177	179	200
Number of groups	20	20	20	23

In experiment 2, the sessions started when there were no less than 7 people in the waiting room who had finished the instruction, with a maximum waiting time of 5 min. In this case, dummy responses were computed by the system which equal to the average response of the round from the participants in the group

2.1.2 Climate Commons Game

In the Climate Commons Game, participants were grouped to play the role of policy directors of different economies in a dynamic environment that is sensitive to the climate. The policy director's job was to set an economic growth target for each year to stimulate or restrain the economy, so as to achieve a long-term economic growth target while keeping global warming at bay. Following classic commons dilemma experiments (e.g., Fehr and Gächter 2000; Hasson et al. 2010), group size was set to 4.

The human-climate relationship (Fig. 1) was verbally described as follows: "Economic productivity affects CO_2 concentration, which in turn affects temperature. Temperature increases make it increasingly difficult to achieve economic growth. Due to time lags in the climate system, the effects of CO_2 on economic growth will only be felt after a considerable delay, after which they will be difficult to reverse. Hence, it is advisable to keep CO_2 concentration from escalating too high". The setup was identical to Sewell et al. (2017; Appendix C).

Once participants read the instructions and correctly answered comprehension questions, they were assigned to a 4-person group and started the game. At the start of each round, each participant received numerical values representing the state of the game: Own Economic Index, the Global Economic Index (sum of all the Own Economic Index values), CO_2 concentration and the global average temperature. Everyone started with their individual economic index of 25, and the initial Global Economic Index of 100 (i.e., 25 × 4). The initial CO_2 concentration was 108 ppm, and the average global temperature of 0.6 °C above pre-industrial levels. Participants did not know the other participants' individual economic indices.

Each director was to set their own yearly economic target using a slider bar that varied between − 1 and + 1. A round ended when all participants made their decisions. The economic indices (each participant and global total), CO_2 concentration and average global temperature were updated, and then a new round began. The game lasted for 70 rounds, which was explicitly mentioned in the instructions. However, because the current round count was not presented on screen, we assume that it would be hard to keep track of the round count. As a result, the end-game effect (Andreoni 1988), where people become more likely to defect toward the end of the game session, is not a large concern in our experiment. At the end of the experiment, participants answered questions about their demographic information. The entire experiment took around 1–1.5 h to complete. See Appendix E for instructions, game interface and a flow-chart illustrating game flow.

2.1.3 Design

In a two-way factorial design, groups were instructed to achieve a different combination of climate and economic goals. One factor was the climate goal of limiting global warming to 2 °C. Half of the groups were given the climate goal, whereas the other half were not. The other factor concerned the framing of the economic goal. In the shared goal condition, groups were told to double the Global Economic Index (i.e. to increase the Global Economic Index to 200 and sustain it); in the individual goal condition, groups were instructed to double their Own Economic Index (i.e. to increase the Own Economic Index to 50 and sustain it). Note that the individual goal condition was economically equivalent to the shared goal condition (i.e. doubling the total economy) if every economy achieved its own goal. This constituted a 2 (shared vs. individual economic goal) by 2 (climate goal present vs. absent) between-sample design.

2.2 Results and discussion

We examined the effects of the climate goal and the framing of economic goal using repeated-measures general linear mixed models (GLMMs), where group was treated as a random effect and an R-side auto-regressive correlation structure was considered. Figure 2 describes trajectories of average individual participant responses (Fig. 2a), Global Economic Index (Fig. 2b), excess CO_2 concentration (Fig. 2c) and global warming (Fig. 2d). Table 2 shows the details of GLMM analysis. Further details are in the Electronic Supplementary (Tables A.1–A.8).

Participants initially increased their economic growth targets, but eventually lowered them as shown by the positive linear and negative quadratic components, presumably to boost their economic indices early while attempting to offset the temperature rise later. Corroborating this observation, the Global Economic Index, CO_2 concentration and the global temperature all show the same pattern of initial rapid increase followed by lower rates of increase. Of interest is the pattern of the Global Economic Index—it peaked around the 30th round, and declined thereafter, in almost all conditions (Fig. 2b)—suggesting that the economic declines due to increasing temperature, restricting economic growth.

Consistent with our H1 and H2, there are significant negative round × climate goal and round × economic goal interactions, showing that the framing of economic goal and climate goal dampen economic growth, thus lowering CO_2 concentration and curtailing global warming. There was no significant three-way interaction, suggesting that the effects of the climate goal and group goal framing were additive.

An interaction effect of the quadratic component of Round and Economic Goal (round^2 × economic goal) was consistently found for all dependent variables. This suggests that the pattern of initial increase and eventual decrease was stronger in the individual goal condition than in the shared goal condition. Those pursuing the individual goal presumably realised the negative environmental impact of their high economic investment at the early stages and tried to reduce their negative impact by rapidly reducing economic growth. However, by the end of their 70 rounds, although the economic index was brought back to a similar level across all conditions, negative climate impacts remained in the individual goal condition. An analogous pattern was found for the climate goal manipulation although the trend was weaker.

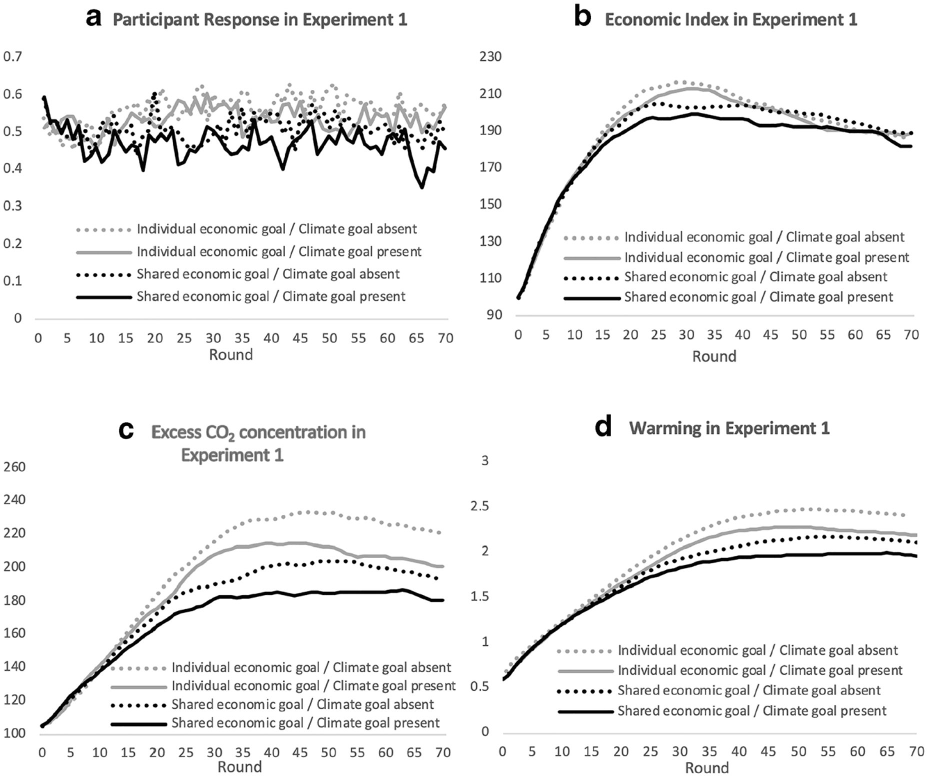

Fig. 2 Average **a** participant response, **b** Global Economic Index, **c** excess CO_2 concentration and **d** warming in experiment 1

Table 2 GLMMs of global economy, excess CO_2 concentration, temperature and participant responses in Experiment 1

	Participant response	Global economy	CO_2	Temperature
	B	B	B	B
Intercept	1.942***	123.910***	93.079***	0.573***
Round	0.019***	4.560***	5.652***	0.069***
Round^2	−0.0002***	−0.056***	−0.056***	−0.0006***
Economic goal	0.044	3.150	11.166	0.110
Climate goal	0.064	2.025	5.779	0.043
Economic goal × climate goal	−0.081	−0.065	−0.457	0.009
Round × economic goal	−0.015**	−0.647***	−1.574***	−0.013***
Round × climate goal	−0.010†	−0.332**	−0.687***	−0.004**
Round × economic goal × climate goal	0.003	−0.109	−0.145	−0.002
Round^2 × economic goal	0.0002*	0.010***	0.015***	9.9E−05***
Round^2 × climate goal	9.8E−05	0.005**	0.004†	4.78E−07
Round^2 × economic goal × climate goal	−4E−05	0.0005	0.004	4.8E−05
Group intercept (covariance)	0.381	588.17	1927.83	0.179

Economic goal: shared = 1, individual = 0. Climate goal: present = 1, absent = 0

***$p < .001$; **$p < .01$; *$p < .05$; †$p < .1$

3 Experiment 2

3.1 Materials and methods

Experiment 1 showed that the goal of mutual cooperation can be facilitated by setting a climate goal and framing the economic growth goal as a collective global target as in the UN Sustainable Development Goals. In experiment 2, we kept the climate goal for all but examined the effect of a shared vs. individual economic goal (H2) as well as that of expectation of mutual cooperation by manipulating whether information about the human-climate system is in a group's common ground (H3). The Climate Commons Game was again used as an experimental paradigm. However, the group size was increased to 10 to see whether these effects generalise to somewhat larger groups, because cooperation in social dilemmas may also be affected by group size (e.g., Shank et al. 2015). We surmised that larger groups may exacerbate the feeling of powerlessness often reported in social dilemmas (e.g., Kerr 1989) and are particularly acute in the climate action (e.g. I am just one among many, and my response will not make any difference; Aitken et al. 2011).

We also explored how the participants managed the twin goals of a stable climate and economic growth because they can be achieved in two different ways. One is for every individual to curtail their own economic growth equally, the other is for some individuals to curtail their own economic growth more than others who grew their economies more than they optimally should have. In the former case, there should not be much economic inequality among the economic units. However, if some players curtail more than others to compensate for those that grow their economy, economic inequality may increase. We explored levels of inequality among participants using the GINI coefficient (Gini 1921)—a well-accepted index of inequality among multiple agents. Its values vary between 0 and 1; the greater, the more unequal. For details, see Appendix D in the Electronic Supplementary and Farris (2010).

3.1.1 Participants and procedure

A total of 741 participants (83 groups, 57.08% male, 21 did not report gender, mean age was 35.52) were recruited from Amazon Mechanical Turk. Numbers of participants and groups in each condition are reported in Table 1.

Participants were asked to play the role of a policy director of one of the 10 economic units. All participants started with their Own Economic Index of 10, which set the Global Economic Index at 100. Each director set their own yearly economic target between −0.5 and + 0.5.

As in experiment 1, all participants were told about the human-climate relationship. However, expectation of mutual cooperation was manipulated. In the common ground condition, participants were told that this information was identical for all participants; in the no common ground condition, they were told that the other players in the game 'may or may not receive the same instruction', and 'you may know some of the things that others don't know, but similarly, you may not know some of the things that others know'. Thus, in the common ground condition, all participants knew the nature of the task, but also knew that everyone had this knowledge, whereas in the no common ground condition, participants were left uncertain about the others' knowledge about the nature of the task; as a result, they would have difficulty in predicting the others' decisions, thus reducing the expectation that the others may cooperate to pursue the global climate goal.

Goal framing was also manipulated. In all conditions, participants were told to achieve the climate goal of limiting global warming to 2 °C. In the shared goal condition, they were told to double the Global Economy, whereas in the individual goal condition, they were told to double their Own Economy. A bonus payment of $1 was promised if participants achieved both the climate and the economic goals. In addition, a bonus payment of 10¢ was promised for each point of individual economic growth they achieved.

Once participants read the instructions and correctly answered all comprehension questions, they were assigned into a 10-person group and started the game. The game lasted for 70 rounds. At the end of the experiment, participants answered questions about the experiment and demographics. Each participant received the sum of three parts of payments: a base payment of $3.5, a bonus of $1 if the goals were achieved and an extra payment for the economic growth they achieved.

3.2 Results and discussion

3.2.1 Economic growth, CO_2 concentration and global warming

We evaluated the effects of goal framing and common ground using repeated GLMMs (Table 3). As in experiment 1, the pattern of economic growth and climate degradation showed a non-linear increase—initial rapid increase followed by a slowdown in the rate of increase—as indicated by the significant positive linear and negative quadratic effects of Round. Again, rapid economic growth was achieved at the cost of environmental damages (Table 3; also see Fig. B.1 in the Electronic Supplementary). For further details, see supplementary materials (Tables B.1–B.14).

Nonetheless, the effect of goal framing was similar to experiment 1: the shared economic goal slowed down economic growth, but also climate degradation—both CO_2 concentration and temperature increased more slowly in the shared goal condition than in the individual goal condition. In other words, more sustainable development was achieved when the economic goal was framed as shared, rather than individuals'.

However, common ground moderated the effect of goal framing and showed somewhat different moderation effects across the economic and climate indices. For the Global Economic Index, a round × goal × common ground interaction was positive and significant, suggesting that the effect of common ground on the growth of the Global Economy differed between the shared and individual goal conditions. A follow-up GLMM analysis for each goal condition showed that sharing common ground facilitates the global economic growth more when the goal was framed as shared, rather than individually pursued (Table 4). In other words, when the goal of growing the global economy was framed as shared by all, sharing common ground helped the global economy grow faster. On the other hand, common ground exacerbated the increase of CO_2 concentration and global temperature in the individual goal condition, but not as much in the shared goal condition. Further analyses showed that common ground exacerbated global warming only in the Individual goal condition (Table 4).

These findings imply an ironic effect of having the information about the human-climate system in common ground. Common ground helps groups sustainably develop when they share the goal of global economic growth, presumably because they can coordinate their economic activities better. However, when each economic unit is pursuing its own growth individually, common ground in fact *worsens* climate change without yielding much economic gain, presumably exacerbating competition among the economies.

Table 3 GLMM of group economy, excess CO_2 concentration, temperature, within-group GINI coefficient in experiment 2

	Participant response B	Global economy B	CO_2 B	Temperature B	GINI B
Intercept	0.226***	99.125***	105.56***	0.739***	0.004
Round	0.002***	1.985***	2.8648***	0.043***	0.006***
Round^2	−1E−05**	−0.011***	−0.017***	0.000***	0.000***
Common ground	0.010	0.387	−0.528	−0.044	0.006
Goal	−0.047**	1.633	−2.554	0.057	−0.006
Common ground × economic goal	−0.025	−2.806	−5.018	0.004	−0.002
Round × common ground	0.0001	0.071***	0.637***	0.007***	−0.001***
Round × economic goal	−0.001	−0.624***	−1.580***	−0.019***	0.001***
Round × common ground × economic goal	0.002**	0.080***	−0.432**	−0.007***	0.001***
Round^2 × common ground	−4.32E−07	−0.001***	−0.004**	−4E−05***	2E−05***
Round^2 × economic goal	1E−05†	0.006***	0.015***	0.0002***	3.41E−06**
Round^2 × common ground × economic goal	−2E−05*	0.001*	0.005**	7E−05***	−2E−05***
Individual intercept (covariance)	0.023	48.863	904.95	0.078	0.001

Economic goal: shared = 1, individual = 0. Common ground: present = 1, absent = 0

***$p < .001$; **$p < .01$; *$p < .05$; †$p < .1$

3.2.2 Inequality

We computed the GINI coefficient to index the level of inequality within each group. First, the GINI levels increased over time, suggesting that some players grew their economies faster than others did. Further, a significant round × economic goal interaction (Table 3) suggests the rate of increase was greater in the shared than in the individual goal condition. This implies that the sustainable development achieved when the goal was shared was attained at the expense of increasing inequality. This occurred because some players curtailed their economic growth more than others did, suggesting a degree of self-sacrifice and altruism by these players. Finally, common ground blunted the increase in inequality in general, but even more so in the shared goal condition than in the individual goal condition. We speculate that this was achieved because the players adjusted their economic growths to coordinate their own economic activities with the overall global economic activities. Note that the players had access to the Global Economic Index as well as their Own Economic Index. Adjusting one's economic growth to make it proportionate to that of the Global Economic Index would be relatively straightforward.

4 General discussion

Successful resolution of the global climate commons dilemma involves a complex balancing act. Not only do we need to balance a stable climate against the need for economic growth, but we also need to ensure that such balance does not come at the cost of widening economic

Table 4 GLMMs of group economy, excess CO_2 concentration, temperature, within-group GINI coefficient by goal condition in experiment 2

	Group economy		Excess CO_2 concentration		Temperature		GINI coefficient	
	Shared goal B	Indiv_goal B	Shared goal B	Indiv_goal B	Shared goal B	Indiv_goal B	Shared goal B	Indiv_goal B
Intercept	100.660***	99.365***	103.250***	105.950***	.796***	.746***	−.002	.004
Round	1.370***	1.961***	1.305***	2.835***	0.025***	0.043***	0.007***	0.006***
Round^2	−0.005***	−0.011***	−0.003***	−0.017***	−0.0001***	−0.0003***	−4E−05***	−5E−05***
Common ground	−2.302	0.248	−5.900	−1.127	−0.041	−.053	.004	.006
Round × common ground	−0.138***	0.102***	0.180***	0.672***	0.0002	.008***	−.001***	−.001***
Round^2 × common ground	0.0002	−0.002***	0.001†	−0.005**	3E−05***	−5E−05**	−2.49E−07***	1.4E−05***
Group intercept (covariance)	51.771	45.716	346.05	1500.86	0.032	0.127	0.001	0.001

Economic goal: shared = 1, individual = 0. Common ground: present = 1, absent = 0

***$p < .001$; **$p < .01$; *$p < .05$; † < .1

inequality. Achieving all these goals presents a challenge, at least within the confines of the Climate Commons Game. Experiments 1 and 2 both showed that, as participants attempt to grow the economy, the CO_2 concentration goes up, and the earth warms up as well. Furthermore, inequality among economic units tends to increase over time (Experiment 2). Although this latter finding needs to be replicated, it suggests that simultaneous maximisation of environmental sustainability, economic prosperity, and economic equality may be a difficult goal to achieve.

Nonetheless, climate change mitigation is not a lost cause. There are some conditions in which the climate-economy balance is sustained to a degree, and the participants' decisions suggest that they are willing to support weaker economic growth for their economy to contain global warming. First, having a clear and shared climate goal appears to militate against pursuing unmitigated economic growth. In experiment 1, consistent with H1, the presence of a climate goal reduced economic growth. Here, the information about the human-climate system was in the group's common ground.

Second, having a shared global economic goal helps people attain more sustainable development, achieving reasonable economic growth while refraining from over-exploitation of the environment. H2 was supported in both experiments. However, sustainable development was achieved in experiment 2 at the cost of increased inequality through voluntary self-sacrifice of individual economies. In the shared goal condition, where the economic goal was framed as a collective and global effort, the relatively lower levels of economic growth were accompanied by increased levels of inequality across players.

Third, the effect of common ground is not straightforward. When a group has a shared economic goal, common ground helps to achieve sustainable development by gaining a greater economic benefit at a relatively smaller cost to the climate, and it reduces inequality within the group. The reduction of inequality, however, is not so large as to make the levels of inequality in the shared economic goal condition comparable with those in the individual goal condition. In contrast, when economic growth is individually pursued, common ground appears to increase the levels of competition among the players without producing much economic gain. It exacerbates CO_2 concentration and global temperature rise, without helping the global economy grow appreciably, although it tends to blunt the rise of inequality to some extent.

In total, a combination of the climate goal, the shared collective goal of global economic growth, and common grounding of the information about the human-climate system may provide the best chance for garnering the public support for sustainable development while containing inequality to a reasonable level. Some may be sceptical about the possibility that all countries, or even a majority of the countries, share a global economic goal; however, this scenario may not be entirely unrealistic. As globalisation deepens, the global interdependence in economic activities across national borders has become obvious as in the case of the Global Financial Crisis of 2007–2009, and the current COVID-19 induced global economic downturn attests. As the reality of economic interdependence becomes clear to everyone, a shared global economic goal may also become a geopolitical reality. There may then be a window of opportunity through which we can achieve satisfactory levels of economic prosperity and equality while containing the global climate within the safe and just operating space (Raworth 2012).

Nonetheless, even in this best-case scenario, rising inequality can present a serious problem for the global community. In the present experiment, some players appear to have voluntarily refrained from growing their economy, and this seems to have increased economic inequality. However, in the contemporary world, there are pre-existing inequalities between countries, and some economies cannot grow as much or as fast, while others may enjoy high economic growth. Such pre-existing inequalities arise out of historical circumstances of unequal distribution of wealth around the world. Rich countries may be able to grow their economies, but poorer economies may not be able to do so, thereby shouldering a more than fair share of the economic burden to manage the global climate commons. Inequalities among countries can undermine the willingness to cooperate in the Climate Commons Game (Tavoni et al. 2011) especially in these circumstances. Addressing such inequality is therefore vital for marshalling global efforts to combat climate change. There are, however, difficult challenges to overcome. At the individual country level, pre-existing inequality, GDP and carbon intensity interact in a complex way to affect CO_2 emissions (Agusdinata et al. 2020). At the global level, there are complex feedback effects of pre-existing inequality on CO_2 emission control and future economic inequality. Institutional arrangements to manage inequality may be critically important at both national and international levels.

The present research has several limitations. Although the Climate Commons Game does capture some of its key components, the real human-climate system is far more complex. First, the scenarios used in the experiments may be further explored. For example, each participant played the role of a sole economic director who can control their entire economy's growth target over many decades. This was done to provide us with a behavioural measure of people's willingness to support different economic policies within their country. Nonetheless, this needs to be further investigated with other methods and potentially different experimental paradigms. We have set a relatively easy climate target, in particular, to contain the temperature rise to 2 °C, rather than 1.5 °C, with the benchmark of the preindustrial level for study 1, but the initial state of the game for study 2. The initial individual economic status was set to be equal across participants so as to best capture the effects of experimental manipulations on people's choices. For practical reasons, we were limited to groups of 10 agents in the game. However, the real-world climate dilemma involves many more agents whose status is not necessarily equal. The effect of inequality should be further examined in future studies. The current game includes only nation-states as main actors, but other non-state actors such as multinational corporations can play a major role in climate politics. The role of non-state actors may also be incorporated into an experimental paradigm.

Second, some aspects of the human-climate model can be improved. For example, economic target and global temperature have a nonlinear but deterministic relationship with the growth of the economy; CO_2 emissions have a nonlinear deterministic relationship with the global temperature rise. Also, our model assumed global climate change hampers economic growth equally across economies, whereas real-world economic impacts of climate change will vary across nations and will depend on factors specific to those nations and their key industries (e.g. Lemoine and Kapnick 2016). A more realistic model of the human-climate system would incorporate uncertainty into these relationships, albeit at the cost of considerable complexity.

Another significant limitation is that the experimental task has only one single track of economy, accelerating or decelerating the economic growth. However, it is possible to pursue policies of ecological modernisation (e.g. Mol 1996; Spaargaren and Mol 1992), where both traditional and ecologically sustainable economic activities (e.g., renewable energy sources) are supported. Regarding economic inequality, our task did not include an institutional mechanism that can allow participants to reduce inequality by redistributing the economic outcomes in some form.

Despite these limitations, the Climate Commons Game has provided some useful insights into the collective dynamics surrounding the global attempt to manage the global climate commons. Of particular importance is the role of common ground in sustainable development and a potential downside to economic inequality associated with the collective management of the global climate commons. Future research should address the critical questions of how institutional and decisional structures can help us manage the climate commons dilemma and inequality.

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