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Climate change: Behavioral responses from extreme events and delayed damages☆

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ABSTRACT

Understanding how to sustain cooperation in the climate change global dilemma is crucial to mitigate its harmful consequences. Damages from climate change typically occur after long delays and can take the form of more frequent realizations of extreme and random events. These features generate a decoupling between emissions and their damages, which we study through a laboratory experiment. We find that some decision-makers respond to global emissions, as expected, while others respond to realized damages also when emissions are observable. On balance, the presence of delayed/stochastic consequences did not impair cooperation. However, we observed a worrisome increasing trend of emissions when damages hit with delay.

1. Introduction

Although scientists have convincingly established a causal link between greenhouse gas emissions and global climate change (IPCC, 2014), the way in which citizens perceive the issue may be simply through the experience of damages. News headlines are generally on the consequences of extreme events such as record temperatures, hurricanes or flooding that are outcomes of pollution and affect specific geographical areas. Another peculiar feature of climate change is the lag built into the earth system between the polluting actions and the system's reaction in terms of climate-related human impacts. Both these features imply a decoupling between polluting actions and their consequences. An usually unspoken argument among politicians and climate change experts is that it will likely take one or more major disasters to motivate citizens and nations to jump start mitigation efforts. Suffering environmental stress may be what can trigger citizens into action to stop climate change more than national plans contemplating changes in emissions. This conjecture motivates our behavioral study.

We focus on the ability to reach ambitious mitigation policies through voluntaristic actions when no binding treaty is in place, such as for example with the scheduling of periodic encounters after the Paris Agreement (Tollefson, 2016). More precisely, we design a climate change game as a *N*-person voluntary public bad game where decision-makers repeatedly interact under a long-run horizon (Dutta and Radner, 2004; Calzolari et al., 2016). Each decision-maker decides on a level of emissions, which brings individual benefits from production and consumption but generates a negative externality to everyone in terms of climate damages. Cooperation entails limiting the level of emissions. Through a laboratory experiment we vary how damages occur across treatments and study its influence on the ability to cooperate. The damage function is one of the fundamental elements for evaluating alternative policies to cope with climate change (Nordhaus, 2010) and has been the focus of a recent debate calling for a need to rethink the way damage functions are designed within Integrated Assessments Models (Wagner and Weitzman, 2015; Stern, 2015). Here we target two critical dimensions of damage functions – the *random* and *delayed* relation between polluting actions and their consequences – because they could both affect the behavioral ability of decision-makers to cooperate. All our specifications of damage vary the riskiness or timing but keep constant the overall level in terms of expected present value. We do so to make easier the empirical comparison across treatments. In a *Stochastic treatment* the damage takes the form of a random accident, whose probability increases in the level of global emissions. This treatment models the consequences of emissions in terms of extreme events, like flooding, droughts, or hurricanes. The aim is not

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to capture a global catastrophe but instead low probability-high impact events that hit a country. We contrast this setting with a *Control treatment* where the damage from climate change occurs deterministically in proportion of global emissions. In a *Delay treatment* the damage is deterministic but hits decision-makers with a delay of two rounds – unlike the other two treatments where current damages depend on current emissions.

While some aspects of the field nicely map into our experiment, we made three major simplifications in order to facilitate participants' understanding of the task and to ease the empirical identification of the effects of the different treatments. First, we model climate damages as a flow externality that linearly increases in emissions, although a more accurate function would be a stock externality with possible non-linearities between emissions and damages (Burke et al., 2015; Dannenberg et al., 2015). A previous experiment showed a negative effect of pollution persistence on the empirical levels of cooperation in the long-run (Calzolari et al., 2016).[1] Second, we consider a limited number of players. Third, we include the deep income inequalities that exist in the field (Nordhaus, 2010; Tavoni et al., 2011) by having two types of participants, rich and poor, who simply differ in their private benefits from emissions.

In all our treatments, monitoring is perfect. After each round of play decision-makers can observe individual emission choices and damages of everyone else. These are propitious circumstances for cooperation to emerge. Under a long-run horizon – like the one considered here – the mitigation of damages may in fact realize under the threat of a punishment activated with the observation of an unexpected increase in others' emissions (the folk theorem, e.g. Fudenberg and Maskin, 1986). Such theoretical result would assume that all individuals follow strategies based on the observation of actions, i.e. emissions. However, individuals may in practice adopt strategies that react to experienced damages rather than actions. The reason may be behavioral, either related to salience or the cognitive costs to process information. On the one hand, damages directly influence payoffs and thus could be more salient to the decision-maker. On the other hand, even when observable, actions have to be interpreted in terms of motivating intentions, particularly when decision-makers form heterogeneous beliefs.

To sum up, greenhouse gas emissions generate delayed, random damages and hence actions (emissions) can be decoupled from their consequences (damages). What motivates this study is the possibility that some decision-makers rely more on experienced damages than actions, which calls for an empirical analysis of how different damage specifications could produce different outcomes in terms of mitigation.

The major result of our experiment concerns the strategies employed by participants in sustaining a cooperative mitigation. We show that participants react both to emissions and damages. In particular, some participants react to the emissions of others, as suggested by a canonical trigger strategy. Other participants, instead, react only to the extreme events or to the realized damages. A third group of participants respond to both emissions of others and individual damages. In Section 7 we conjecture on how the presence of these different types of individuals can relate to the differences in the overall cooperation levels we detect, in particular the withstanding levels of cooperation with stochastic and delayed damages and the increasing trend of emissions in the latter treatment.

The paper proceeds as follow. Section 2 places the contribution within the context of the literature about experiments on climate change and long-run cooperation. Section 3 presents the formal setup and experimental design. Section 4 puts forward some theoretical considerations about equilibrium predictions. Section 5 explains how the experiment was run. Section 6 describes the main results about aggregate emissions and strategies, while Section 7 discusses the results, some policy implications and concludes.

2. Related literature

We contribute to two branches of the literature, one on climate change and another about sustaining long-run cooperation.

There exists a small but growing experimental literature on mitigation policies for climate change.[2] Some experiments model climate change as a problem of sustaining cooperation when facing an emission thresholds that may activate a catastrophe, while others, including the present one, model it with an incremental damage from pollution. Among the former category, the pioneering study is Milinski et al. (2008), who show that a higher probability of a catastrophe reduces emissions in the presence of a known tipping point. This result becomes weaker if the location of the tipping point is random, and more so in case of ambiguity (Barrett and Dannenberg, 2012, 2014; Dannenberg et al., 2015). Income inequality and the ability to communicate also affect the frequency of avoiding a catastrophe: Tavoni et al. (2011) show that groups that manage to reduce inequality during the play are the most cooperative, especially when communication is possible.

The experiments with a gradual impact of pollution on damages are relatively more recent. Sherstyuk et al. (2016) compares overlapping generations versus long-lived agents and reports that cooperation is harder to sustain for overlapping generations; Pevnitskaya and Ryvkin (2013) contrasts finite and indefinite horizons and find that participants learn to cooperate faster in the former setting, although they experience a last round drop; finally, Calzolari et al. (2016) study pollution persistence in a dynamic setting and show that it does not hamper cooperation per se but report a declining trend of cooperation for higher stocks of pollution. The novelty in our experimental design is to decouple actions and their consequences on damages, which in most studies are instead associated and indistinguishable. Our aim is to uncover the behavioral responses in a setting that replicates these key features present in the field.

The contribution of our paper to the vast literature about sustaining cooperation in repeated games rests on the distinction and observability of actions (emissions) and their consequences (damages). When the "shadow of the future looms sufficiently large", cooperative outcomes can be obtained, possibly also the socially optimal outcome, with strategies punishing actions that deviate from a cooperative norm (Friedman, 1971; Dal Bó and Fréchette, 2017). Beginning with Green and Porter (1984), Abreu et al. (1990), Fudenberg et al. (1994), and Dutta (1995), the standard folk theorem has been extended to the case in which decision-makers do not perfectly observe others' actions, either because actions are observed with delay, as in our Delay treatment, or because observability only refers to an imperfect signal, such as the accident realization in our Stochastic treatment. Applying these results, we experimentally show that although the temptation to deviate from cooperation is generally stronger for strategies based on damages than emissions, cooperation could still be sustained when participants value sufficiently the payoffs from future interactions.

Some experimental papers on cooperation are related to our study. Bereby-Meyer and Roth (2006) study a repeated game with observable actions where outcomes can be either deterministic or probabilistic, depending on treatments. Relying on the psychological concept of "reinforcement" (Robbins, 1971), they report how a deterministic environment, granting a systematic reinforcement in the learning process, fosters cooperation as compared with the partial reinforcement available with random outcomes. Fudenberg et al. (2012) study the effects on cooperation of errors in implementing intended actions. They show considerable diversity in strategies, as we document in our analysis, and that successful strategies are "lenient" and "forgiving": unexpected actions are not immediately punished, with attempts to restore cooperation. Camera and Casari (2009) manipulate monitoring of individual

[1] Another dimension of the damage function that we do not consider here is its intergenerational feature (Sherstyuk et al., 2016).

[2] Although experiments on climate change face challenges of external validity, they play an important role integrating and complementing theory and field data. One definitive advantage of laboratory experiments is the possibility to control the environment and manipulate parameters, which enables to identify causal effects (Falk and Heckman, 2009).