CO_2 Emission Reduction – Real public good provision by large groups in the laboratory

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Abstract

Public good experiments are usually conducted in the laboratory using the voluntary contribution mechanism (VCM). We use a real public good (CO_2 emission rights) with comparatively large groups (up to 60 subjects) and compare the results with corresponding experiments based on the VCM. Our treatment variations include group size and the feedback that subjects receive after each round. Our data reveal that, in contrast to the VCM, subjects dealing with a real public good relate their decisions to those of their group members in the lab only in the first rounds and do not change their contributions thereafter. These observations suggest that, when faced with a real public good, subjects use the whole group, including "players" outside the lab, as a main reference point. In this way, contributions made to the real public good in the lab tend to depend on the salience of mutual cooperation benefits existing outside the lab. Our findings help to understand the transferability of previous laboratory research on the VCM to real public good provision.

Keywords: public good experiments, large groups, information, emission rights

JEL-Class.-No.: C91, C72

Declarations of interest: none

Funding: This work was supported by DFG (Deutsche Forschungsgemeinschaft, grant numbers WE 2027/10-1, WE 2027/10-2).

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1. Introduction

Some of the most important and at the same time most difficult challenges for societies are essentially cooperation problems of large groups. The outstanding example of our time is climate change. The global public good of "climate protection" can only be offered if many make a voluntary contribution. From the point of view of a selfish individual, however, this is not a rational strategy. Besides environmental protection, there are other very important cooperation tasks. A functioning democracy can only be maintained if enough citizens are willing to participate in the processes of democratic decision-making. Peace missions by coalitions of individual countries or the UN are another example. The maintenance of an international free-trade system or the merger of states into a common market (as in the EU) also bears the traits of a public good problem. And, not least, establishing herd immunity against COVID-19 has elements of a public good problem.

Against this background, it is not surprising that economic research deals with the problem of collective goods in many ways. A strong line of literature, starting with Marwell and Ames (1979, 1980), uses laboratory experiments to investigate the conditions under which public goods can be offered privately. The experimental paradigm that has prevailed in the analysis of cooperation problems goes back to Isaac et al. (1984). It uses the so-called voluntary contribution mechanism (VCM) to represent the typical incentive problem that arises in the provision of public goods. A group of people has to decide simultaneously how much each of them wants to contribute to a public good. Each contribution benefits all group members alike regardless of whether they have contributed or not. A money-maximizing individual will free ride completely, not contributing anything to the public good, while group welfare is maximized if everyone contributes.

The VCM in most public good experiments typically employs small groups of less than 10 subjects and, consequently, involves a rather high marginal per capita return (MPCR) for each group member from investing in the public good.[1] The above-mentioned examples of socially relevant real cooperation problems refer to very large groups, however, where the individual benefit from cooperation is in fact very small, sometimes negligible. Understanding how large groups actually solve real cooperation problems is the main goal of experimentally analysing

[1] Analysing very low MPCRs is not possible in small-group VCMs due to the parameter restrictions defining a social dilemma situation in a VCM. The dilemma implies that in a VCM, where the marginal return on the share of the individual endowment that is not invested in the public good is normalized to 1, the MPCR has to be *smaller* than 1 (so that investing in the public good is less profitable than not investing), but *larger* than the reciprocal value of the group size (so that investing in the public good is efficient from the group perspective). For more details see Appendix A.

the private provision of public goods. To this end, recent studies tackled the large-group cooperation question and conducted VCM experiments involving groups of up to 100 members and more (see, for instance, Weimann at al. (2019) for a systematic study and the literature review in Section 2). It is not clear, however, to what extent results from research on large-group VCMs can be transferred to the provision of *real* public goods (RPGs).[2] So far, there is a lack of comparison studies that investigate large-group real public goods provision using a design similar to VCM experiments. In this paper, we attempt to reduce this gap by analysing data of a controlled laboratory experiment that systematically compares in a between-subject design how large groups provide monetary public goods using the VCM mechanism and how large groups provide a real public good. The real public good in our study is the reduction of CO_2 emissions. This reduction is achieved by using subjects' monetary contributions to buy and withdraw CO_2 emission certificates traded in the European Union Emissions Trading System. We use CO_2 emission allowances as a real public good in our experiment because they are an important tool in reducing global warming; and they are easy to handle in our controlled experimental setting. Moreover, as CO_2 emission reduction was and still is a pressing topic in the media and in the social discussion in Germany, the salience of mutual cooperation benefits could be expected to play a decisive role in our participants' decisions.

Two stylized facts resulting from repeated VCM experiments with small groups are particularly important for our research. First, the cooperation problem can be partially solved since small groups are able to realize about 30-40% of the efficient cooperation performance.[3] Second, contributions tend to decrease over time.[4] Recently, two important insights on cooperation behaviour have been published that are highly relevant for this paper. Fischbacher and Gächter (2010) provide an explanation for the observed decrease in contributions, which is based on the observation of *imperfect* conditional cooperators, who cooperate as long as others cooperate, yet do not fully match the average contributions.[5] The authors particularly demonstrate that the

[2] The term real public goods is used by, for instance, Levitt and List (2006, 2007). Other terms are, e.g., non-laboratory or real-world public goods (Brown and Taylor, 2000), naturally occurring public goods (Laury and Taylor, 2008). CO_2 reduction is also referred to as a global public good (e.g., Barret, 2007; Tavoni et al., 2011; Löschel et al., 2013; Uehleke and Sturm, 2017; Sturm et al., 2019).
[3] For an early overview of experimental findings see Ledyard (1995), and for a more recent selective survey see Chaudhuri (2011).
[4] Other important findings are, for example, that punishment and communication are effective instruments to promote cooperation (cf. Fehr and Gächter, 2000, and Brosig et al., 2003).
[5] Other types observed by Fischbacher and Gächter (2010) include free riders and triangle cooperators. The latter are conditionally cooperative subjects who increase their contributions with increasing cooperation of others up to a point but decrease their contributions after this point. Similar observations have been made by Fischbacher et al. (2001), Keser and van Winden (2002), Burlando and Guala (2005), Kurzban and Houser (2005), Bardsley and Moffatt (2007), Kocher et al. (2008), Muller et al. (2008), Duffy and Ochs (2009), and Herrmann and Thöni (2009) (cf. Fischbacher and Gächter (2010), footnote 2).

decrease in contributions is not driven by the beliefs that subjects hold about others' contributions, but by the preference for imperfect conditional cooperation. Indeed, subjects' beliefs adapt to the declining contributions. According to Fischbacher and Gächter (2010), behaviour in a public good experiment can be described as follows. After the first round, the players learn how much the group has invested in the public good on average. In the second round, imperfect conditional cooperators (ICCs) choose a contribution that is below average. Given a relatively large share of ICCs, this leads to a lower average contribution in the second round. If the players receive feedback on the behaviour of the other players, this results in a further decrease in contributions in the next round because the ICCs now adapt to the lower average. The theory of Fischbacher and Gächter does not allow the prediction of contributions made in the first round or of the level of overall contributions, but explains convincingly why contributions decrease during the experiment.

While Fischbacher and Gächter investigate behaviour in small groups, Weimann et al. (2019) systematically analyse public good provision in large groups with up to 100 members. In particular, they study the influence of – the now possible – very small MPCRs on cooperation.[6] One of the central theses in Mancur Olson's book *The Logic of Collective Action* (1965) states that large groups confronted with a small individual benefit from cooperation will hardly be able to offer collective goods since the small influence of the individual group member ultimately destroys the incentives for cooperative behaviour. However, public good experiments with relatively small groups (group size N between 4 and 10) have shown that for a given MPCR, increasing the size of the group does not cause contributions to fall. In addition, the group size effect is shown to depend on the level of MPCR. For relatively small values of 0.3, the effect of increasing the size of the group is positive and strong, but for large MPCR (values of 0.75 or 0.8) it is weak and mostly insignificant (Isaac et al., 1984, 1988, 1994; Nosenzo et al., 2015).

The results of Weimann et al. (2019) support these observations and confound the thesis of Olson. The authors observe that cooperation rates and dynamics of cooperation in groups with 100 members and a low MPCR of 0.04 are very similar to those in small groups with eight members employing a relatively high MPCR of 0.25. Furthermore, large groups respond very sensitively to small changes of the low MPCR: at a value of 0.02, average cooperation is considerably lower than at 0.04. Weimann et al. (2019) provide and successfully test an explanation for these findings. For a given group size, cooperation under the VCM is more likely the larger

[6] Why a small MPCR is not possible in small-group VCMs is explained in footnote 1 and Appendix A.

the distance between the chosen MPCR and its lower bound (which is 1/*N* when normalizing the marginal return from a private investment to 1, see Appendix A). This MPCR-distance can therefore be interpreted as an indicator of the salience of the cooperation problem. In particular, 1/*N* is the weight that one member has in a group of *N* persons. The MPCR-distance tells us how much the group member's marginal return from the public good exceeds this weight. If the MPCR-distance is very small (the chosen MPCR is close to 1/*N*), the problem and the necessity for cooperative behaviour are not very salient and average contributions should be low. With increasing MPCR-distance, the social dilemma and, thus, the benefits from mutual cooperation become more salient and average contributions should increase. In line with this explanation, Weimann et al. (2019) observe a positive relationship between average contributions and MPCR-distance.

We may thus conclude the following. First, Fischbacher and Gächter (2010) have paved the way for a deeper understanding of the role of preferences and expectations in public good experiments. Second, Weimann et al. (2019) show that cooperation is possible even in very large groups, i.e., under conditions that are typical for real public goods, and that the salience of the mutual benefit from cooperation is decisive in this context. Despite these insights, the scientific evidence is still insufficient to provide a reliable picture of what happens when large groups of people provide real public goods and of how efficient cooperation can be promoted in these cases. In this paper, we try to take a step in this direction by conducting a laboratory experiment with a real public good (CO_2 emission reduction) and by comparing observed behaviour to that in a VCM experiment.

Our findings show that in order to understand real public good problems in the laboratory, issues have to be clarified that have not been on the scientific agenda so far. In a laboratory VCM-experiment, Weimann et al. (2019) demonstrated that group size (*N*) and MPCR determine the salience of mutual cooperation benefits. When real public goods outside the laboratory are involved, it is not clear what this salience depends on. In this context, the role of information on the behaviour of other participants in the experiment might become important. For this reason, we have varied whether participants receive feedback on other group members' behaviour or not. We find that responses to feedback are sensitive to whether the VCM or the RPG condition is played. In the RPG experiment we do not see the decay of contributions typical of VCM experiments. We argue that, in our global (real) public good setup, subjects in the laboratory make contributions conditionally upon the whole group, including "players" outside the lab.

We proceed as follows. After a short survey of related literature in Section 2, we derive our hypotheses in Section 3. Section 4 presents the experimental design and Section 5 contains the results. Section 6 concludes and discusses our results.

2. Related literature

Our paper is linked to several strands of the literature. The first strand relates to group size. Group size may matter for cooperation because the small benefit of a single group member in a large group may ultimately destroy the incentives for cooperative behaviour. This is one of the central theses in Mancur Olson's book *The Logic of Collective Action* (1965). But, as already mentioned, the literature shows that the interplay between group size and MPCR matters. Isaac et al. (1994) implemented a treatment in which groups of 40 faced an MPCR of 0.03. Compared to treatments with the same number of group members but a much higher MPCR (0.30 or 0.75), Isaac et al. (1994) find a lower initial average contribution and a much faster decay of average contributions. Diederich et al. (2016) conducted an online VCM experiment with group sizes of 10, 40, and 100 subjects and a large MPCR of 0.3. They find a positive group-size effect in that larger groups reach higher degrees of efficiency. Weimann et al. (2019) analysed the interplay of group size and MPCR in a VCM study involving groups of eight, 20, 30, 40, 60 and 100 members. The MPCRs are 0.25, 0.12, 0.06, 0.04, and 0.02, depending on group size and treatment. The authors find rather similar dynamics in small groups of eight and large groups of 60 and 100 members and an MPCR of 0.04. The group-size effect and the MPCR effect are positive. In all groups a similar pattern of contribution decline is found. The systematic design of different combinations of group size and MPCR allowed the authors to develop the MPCR-distance hypothesis, saying that the difference between the *MPCR* – the amount a group member receives from investing one euro cent into the public good – and the minimal MPCR necessary to create a public good problem ($1/N$) provides a measure for the advantageousness of joint cooperation (see Appendix A.2 for a more detailed description). Weimann et al. (2019) provide evidence that the MPCR-distance has high explanatory power.[7]

[7] Large-group experiments also become more common in other research fields. Arifovic et al. (forthcoming) conducted a bank-run game with groups of 10 and 75–90 participants and find systematic group size differences that theory fails to predict. They show that large groups are sensitive to the salience of riskiness of the mutually beneficial strategy. Hommes et al. (2021) do not find group size differences in bubble formation across small and large groups (6 to 104 participants) and observe both stable and unstable markets for both group sizes.

An important study using field data is Zhang and Zhu (2011), who investigate the relationship between group size and individual-level contribution to the real public good 'open content production' in Wikipedia. In a natural experiment, an exogenous shock was induced by the Chinese government blocking access to Wikipedia for about a year. In this large-group setting, Zhang and Zhu find a positive relationship between group size and Wikipedia contributors' contribution levels. In addition, they find that contributors who are likely to care more about social benefits react to the change more strongly than those who value them less.

A second strand relates to climate-change mitigation. Goeschl et al. (2020) employ different combinations of group size (3, 10, 15) and MPCR (varying from 0.1 to. 0.8). In a within-subject design they compare decisions made in an abstract public good experiment (VCM) to those made in an unrelated individual decision task of climate change mitigation in which subjects could buy and delete CO_2 emission rights. The findings suggest that cooperation in the VCM is only weakly linked to investments made in CO_2 emission rights. The authors conclude that standard VCM experiments fail to capture many idiosyncratic factors that are candidate drivers of individual voluntary climate action decisions. It is not implausible, however, that the missing correlations could be due to the rather different structure of the decision tasks. Our study will make the RPG design as similar as possible to the VCM by using identical instructions in both games, except for different payment functions and CO_2-reduction-specific information in the RPGs.

We are not aware of any large-group real public goods experiment featuring a climate change scenario, but some small-group social dilemma experiments do exist. Milinski et al. (2006, 2008), for instance, introduce the collective-risk social dilemma (CRSD) and conduct threshold public good experiments framed in a climate change situation. As in our RPG experiment, contributions to the public good "climate account" are not refunded to the participants. They are invested in public information about climate change prevention. Participants face the threat that their private account, i.e., the amount not invested, will be severely reduced if the group does not reach the threshold. In the CRSD studied by Tavoni et al. (2011), subjects' contributions to the climate account are, as in our RPG experiment, used to buy and withdraw CO_2 emission certificates traded in the European Union Emissions Trading System (EU ETS).[8] The above-mentioned studies show that participants seem to care about climate-change reduction: they contribute to the real public good and in many groups the threshold is reached, even though

[8] To the best of our knowledge, Tavoni et al. (2011) is the only experimental CRSD study using investment in CO_2 emission certificates.

subjects do not receive a refund from the public good. Note that, in contrast to our study, participants in the CRSD face the threat of losing private income if the threshold is missed, which potentially has increased their contribution rates.

Other studies directly ask subjects how much they are willing to pay for the global public good of CO_2 emission reductions in one-shot and mostly individual decision-making situations. These studies also show that subjects have preferences for contributing to climate change mitigation. Participants' degrees of willingness-to-pay (WTP) are inferred from, for example, the share of the monetary endowment they spend on buying CO_2 emission rights, which are then withdrawn from the trading system by the experimenter. In Goeschl et al. (2020), for example, average WTP ranges from about 30 percent of the endowment for students to 50 percent for non-student subject pools.[9] Uehleke and Sturm (2017) report significantly lower WTPs when subjects have to spend their own money than when they make hypothetical decisions.

A third strand of literature we are contributing to studies the impact of information on participants' behaviour in (public good) experiments. For one thing, being provided with feedback is a necessary factor in influencing the interplay between beliefs and the preference for imperfect conditional cooperation (Fischbacher and Gächter, 2010). However, how do people behave in repeated VCM experiments if no feedback is provided? Empirical evidence is rare. Moreover, it is inconclusive in that both declining contribution dynamics as well as stable contribution behaviour over time have been found. If feedback is provided, contributions seem to be heavily influenced by which kind of feedback is given about contributions: own (A); group's total (B); sum of other group members' (C); group average (D); graphical (E); individual contributions of all group members (F); or some combination of the former. Sell and Wilson (1991) compare a no-information treatment with a combination of (A) and (B) as well as of (A), (B), and (F). No-info and AB show rather stable patterns with a declining trend in the last two periods. In both treatments, the dynamics of contributions are nearly identical and average contributions are significantly lower than those in ABF. Neugebauer et al. (2009) contrast a no-feedback treatment with an AC-information treatment and elicit beliefs on the other group members' contributions in each round of both treatments. The average contributions and guesses are significantly larger in No-info than in AC. Cooperation remains at initial levels over ten periods,

[9] Similar studies are Diederich and Goeschl (2014, 2018), Goeschl and Perino (2012), Löschel et al. (2013, 2017, 2018), and Lohse et al. (2017). Sturm et al. (2019) run WTP experiments using two Chinese CO_2 emissions trading schemes. Except for CO_2 emissions, studies involved a rather diverse range of real public goods, such as supporting the broadcast of a new television show (Bohm, 1972), access to a future service market (Bohm, 1984), purchasing and protecting rainforest land (Brown and Taylor, 2000), press advertisement on climate protection (Milinski et al., 2006, 2008), and planting trees (Laury and Taylor, 2008).

while contributions and beliefs decline in the information condition. Pereda et al. (2019) run VCMs with 100 and 1,000 participants in treatments with AD, AE, and ADE information. Unfortunately, there is only one independent observation in AD and two independent observations in the other two treatments. With group sizes of 100 and 1,000, the authors observe increasing contributions in the first three rounds of AD and a general decay in contributions afterwards; the dynamics are nearly indistinguishable between the large group and the smaller group. When information is provided on distributions in addition to group averages, contributions are higher and, averaged over both observations, seem to increase for a number of rounds before decreasing. For a discussion of other types of feedback (e.g., informing on the highest or lowest individual contribution), see Irlenbusch et al. (2019) and the literature reviewed therein.

Our study also relates to research dealing with the effects that providing additional information might have on subjects' WTP for reducing and eliminating CO_2 emissions. Löschel et al. (2017) provide their participants with information on the behaviour of subjects in a previous study (Löschel et al., 2013). They find no difference in the levels of WTP compared to the no-information condition, but they do find higher levels of WTP than in the 2013 study. Sturm et al. (2019) ask participants about their WTP when increasing percentages of subjects in a session contribute to eliminating CO_2 emissions. They find significantly higher levels of WTP with increasing cooperation of others. The literature on how social information on charitable giving affects behaviour is also relevant, because charitable giving might incorporate a public good problem.[10] Shang and Croson (2009), for example, found that social information may change people's cooperation behaviour in an on-air fundraising campaign for a public radio station. They observed not only that more social information significantly increased individual contributions but also that it did not crowd out future contributions. Shang and Croson conclude that individuals appear to use others' contributions as a signal of the appropriate or necessary contribution level in order to achieve the fundraising goals. Similarly, Frey and Meier (2004) conducted a field experiment during the yearly fund-raising campaign at the University of Zürich. They found a significantly positive effect of social information on the probability to donate, which they interpret as conditional cooperation.

[10] If the well-being of others is an argument of the utility function, this offers a free-riding opportunity because it does not matter who makes the "others" better off.

3. Research questions and hypotheses

Our research questions concern the private provision of a real public good in the laboratory. The *real* public good to which the participants in our experiment contribute comprises the reduction of CO_2 emissions. We use their monetary contributions to buy and withdraw CO_2 emission certificates traded in the EU ETS. Buying and withdrawing emission permits reduce CO_2 emissions by exactly the number of tons for which rights are bought. The first and very fundamental question is whether subjects are willing to cooperate in an experiment in which contributions are used to buy and decommission emission rights. Our literature review has shown that subjects are absolutely willing to contribute to climate change mitigation even if they receive no direct monetary return from their investment. This holds under social dilemma conditions in small groups (Milinski et al., 2006, 2008; Tavoni et al., 2011) as well as in individual decision contexts (e.g. Goeschl et al., 2013, 2017, 2018, 2020, or Sturm et al., 2019). But it is not clear if this also holds under the conditions of a large-group real public good experimental design.

If an individual makes efforts to reduce his/her personal carbon dioxide emissions, this will have almost no effect on the climate because the climate system only reacts to large-scale changes. Thus, it is very plausible that the MPCR is perceived as almost zero. Thus, not only Olson's theory on collective action but also the experimental literature would suggest only very little cooperation, if at all, under these conditions. At this point, the findings in Weimann et al. (2019) become important. They show that significant cooperation can also occur when the MPCR is very small. However, this requires that people be sufficiently aware and sure that cooperation leads to mutual benefits. According to the explanation of cooperation in large groups by Weimann et al., the salience of mutual cooperation benefits plays a decisive role. In Germany, global warming is an important topic in the media and in social discussion. Assuming that the salience of the mutual benefits of CO_2 emission reduction is determined outside the lab, we thus expect that this salience is quite high. Following Weimann et al. (2019), this implies that subjects should be willing to contribute.

The second question relates to the decreasing dynamics of cooperation. Following Fischbacher and Gächter (2010), these dynamics are the result of imperfect conditional cooperation. The central question in this context is: on whose behaviour do subjects condition their decisions with regard to the real public good in the laboratory? There are two groups of players that might be considered: the group of subjects involved in the experiment and the group of those who contribute to climate protection outside the laboratory. There are two important differences between these two groups.

First, in the laboratory, the average contribution of other subjects can be easily observed. In real-world contexts, this is much more difficult. For example, it is difficult to estimate the average amount of effort people put into climate protection since this protection is carried out by voluntary private actors as well as through governmental coercion. Private efforts, in particular, such as turning down the heating or abandoning the car, cannot be easily specified. The second difference is that from the perspective of the laboratory subjects, the average contributions made by people outside the laboratory are exogenous, i.e., their contributions do not respond to laboratory subjects' behaviour and remain constant during the experiment. In contrast, the average contributions made inside the laboratory might be responsive and can change over time.

The point we want to make is that imperfect conditional cooperators can be oriented towards either group: those participating in the lab experiment or the large group outside the lab. We cannot observe directly which one they choose, i.e., we need to formulate a hypothesis: Since the real public good is provided by the large group including the many "players" from outside the lab and not only by the small group in the lab, imperfect conditional cooperators will take their cue from the large group. This means that, on average, they will choose their own contribution somewhat below the average of the generally perceived cooperation outside the lab. Still, in the first round, they do not know for sure how much of the 120 cents an average resident of the planet, were he/she in the lab, would invest in the public good. Therefore, ICCs will use the average first-round contributions of the lab participants as an estimate of what an average person outside the lab would do and, on average, they will adjust their contributions accordingly.[11] In the second round and beyond, the contributions of the other group members inside the lab no longer serve as an indicator of what happens outside the lab because no adjustment to an individual's contribution occurs there. Therefore, the contributions of the other participants in the lab in subsequent rounds no longer matter for the decisions of the ICCs because they have no information on average contributions outside the lab.

If this hypothesis were to be true, it would have an important implication for the contribution dynamics observed in our RPG experiment. In particular, despite the first-to-second round, contributions should not fall in the course of the experiment, independent of whether feedback about others' behaviour is provided or not, since subjects' behaviour should be independent of the behaviour of their group members. Also, the size of the group inside the lab should not

[11] See Frey and Meier (2004), Shang and Croson (2009), Croson et al. (2009).

influence contributions. This is in contrast to Weimann et al. (2019), where in the VCM experiment, the group size had a strong influence in that, ceteris paribus, the larger the group, the more the participants cooperated. With regard to the VCM experiments, we conjecture that in a feedback condition the usual decrease in contributions is observed. In a no-information scenario, we expect that contributions stay constant, as group members receive no feedback to compare their behaviour with.

Given our above argumentation, our conjectures about the differences between VCM experiments and RPG experiments can be summarized as follows:

Hypothesis 1 (VCM versus RPG):

In a laboratory RPG experiment,

a) the decay of contributions over the course of the experiment is less pronounced and
b) the group size effect is smaller than in a VCM experiment.

Hypothesis 2 (Feedback):

a) In an RPG experiment and a VCM experiment without feedback, contributions will not change significantly in the course of the experiment.
b) In an RPG experiment with feedback, average contributions will only change after the first round.

4. Experimental design

To test our hypotheses we analysed data of RPG and VCM treatments with and without feedback. To meaningfully compare the outcomes of the RPG and VCM experiments and to avoid framing effects, we made the designs of the RPG and VCM treatments as similar as possible. We used identical instructions, with the exception of the different payment functions, CO_2 reduction and decommission-specific information in RPGs (see Appendices B.1 and B.2).

We conducted RPG treatments with groups of 60 and 30 subjects who may individually decide either to spend (part of) their endowment on buying carbon dioxide emission rights and thus eliminating them or to keep the endowment for themselves; see treatments T1 and T2 in Table 1. Furthermore, we ran the same RPG experiment with a group of 30 subjects, in which subjects received no feedback about their own and others' behaviour (treatment T3). In addition, we used VCM (with feedback) data of treatments with group sizes of 60 and 30 subjects, provided by Weimann et al. (2019); see treatments T4 and T5 in Table 1. Finally, we ran a VCM experiment with a group of 30 subjects without feedback (treatment T6). In total, we have six treatments (Table 1) conducted in 2012 and 2013.

Table 1

Treatments.

Treatment	Group size	MPCR	Sessions / # of ind. obs.	Feedback	Lab
T1 (60-Emission)	60	<<0.01	8	Yes	Connected
T2 (30-Emission)	30	<<0.01	8	Yes	Connected
T3 (30-Emission nF)	30	<<0.01	2/58	No	Magdeburg
T4 (60-0.06)	60	0.06	8	Yes	Connected
T5 (30-0.06)	30	0.06	8	Yes	Connected
T6 (30-0.06 nF)	30	0.06	1/30	No	Magdeburg

Notes: The data of treatments T4 (60-0.06) and T5 (30-0.06) are provided by Weimann et al. (2019).

The basic design of all treatments is a standard ten-round public good game. The initial endowment in each of the ten rounds was 120 euro cents. All four feedback treatments were run simultaneously in the laboratories of the Universities of Bonn, Duisburg-Essen, Göttingen, and Magdeburg (all located in Germany, see Fig. 1). We applied the connected-lab method and subjects were equally distributed over the four laboratories.[12] The four laboratories were connected via the Internet. All the treatments were coordinated by the laboratory in Magdeburg. The communication between the laboratories took place via Skype. When entering the respective laboratory, the subjects could see a (soundless) video conference of the four laboratories on a computer screen. Thus, each subject had the opportunity to verify that all the laboratories were indeed connected and working simultaneously. At the beginning of each treatment, the subjects received written instructions (see Appendix B). Before the start of the first round of the game, they had to answer several questions concerning the payoff rules in order to ensure that they had understood the game correctly.

[12] In Weimann et al. (2019), we tested in a small-group experiment whether the connected-lab design had an influence on subjects' behaviour. Eight subjects played a VCM experiment locally in the four labs. We compared the results with a connected-lab treatment with two subjects in each lab and found no significant differences.

In the feedback treatments, the subjects were informed about the amount they had kept, their own contribution, the average contribution to the public good of all group members, their individual payoff from the public good, their individual earnings in the round just completed, and the cumulated earnings over all completed rounds after each round. In the no-feedback treatment, they received none of this information. In all the treatments, the subjects knew that after ten rounds the experiment would be finished. The subjects were then paid in cash and left the laboratories. The sessions lasted about 90 minutes and the average earnings were 15.36 euros. The experiment was programmed using zTree (Fischbacher, 2007) and the recruitment of subjects took place at each of the four locations by ORSEE (Greiner, 2015).

Fig. 1 The location of the four laboratories in Germany

Three of the six treatments differed from the VCM design with respect to the public good that had to be provided by the subjects. In T1 (60-Emission), T2 (30-Emission) and T3 (30-Emission nF), the subjects could decide either to keep the endowment of 120 euro cents or to spend it (or parts of it) on the purchase of CO_2 emission rights from the EU ETS. Before the experiment started, the subjects were informed about the extent and effects of the EU ETS at the time of the experiment (see Appendix B.1). In particular, they were informed that buying and withdrawing emission permits reduces CO_2 emissions by exactly the number of tons for which the rights were bought. Furthermore, they were informed that the average per capita CO_2 emissions in Germany were about 12 t/a and the current price for a ton of CO_2 emissions was about 7 euros at the time the experiment was conducted. In addition to the feedback participants received in the VCM treatments, subjects were informed in the RPGs in each round about the amount of CO_2 that had already been decommissioned by the contributions. To ensure that the subjects trusted us that all the money spent really was used to buy permits, every subject received a statement, personally signed by the experimenters, in which they committed themselves to buying the permits and to making the climate certificates public (see Appendix C). The documents (Appendix D) were then published on the website of the four labs, proving that the purchase had taken place and the rights had been deleted. In T1 (60-Emission) the group size was 60 and in T2 (30-Emission) it was 30. Because it is very unlikely that climate change is influenced by the marginal reductions in CO_2 arising from the contributions in our experiment, the MPCR in the emission-rights treatments is very close to zero.

In T3 (30-Emission nF), we repeated the emissions experiment with 30 subjects in a no-feedback (nF) version in which subjects did *not* receive any information on contributions, already decommissioned CO_2, and payoff, regarding either their own or those of other players. In T6 (30-0.06 nF), we ran a similar no-feedback treatment with a group size of 30 using the VCM and an MPCR of 0.06. T4 (60-0.06) and T5 (30-0.06) are the corresponding VCM *with* feedback information and group sizes of 60 and 30, respectively. T3 (30-Emission nF) and T6 (30-0.06 nF) were conducted in Magdeburg only. Note that in the no-feedback treatments, each individual decision can be treated as a statistically independent observation because, different from feedback treatments, subjects were ignorant of their own and others' contributions and payoffs.

5. Results

5.1 Description and nonparametric analysis

Table 2 summarizes the average contributions over all the rounds as share of the endowment across the six treatments. It also contains the average contributions in rounds 1 and 10 as well as the controls for age and gender used in the regressions presented in the following subsection.

Table 2

Summary statistics (mean values, standard deviations are given in parentheses).

Treatment	Contributions			Age	Female
	Round 1	Round 10	All rounds	in years	dummy
T1 (60-Emission)	0.263	0.234	0.209	23.502	0.483
	(0.025)	(0.035)	(0.023)	(0.301)	(0.083)
T2 (30-Emission)	0.251	0.195	0.187	23.442	0.550
	(0.026)	(0.043)	(0.031)	(0.293)	(0.071)
T3 (30-Emission nF)	0.272	0.314	0.265	22.569	0.431
	(0.266)	(0.309)	(0.226)	(3.009)	(0.500)
T4 (60-0.06)	0.404	0.103	0.260	22.723	0.494
	(0.054)	(0.031)	(0.046)	(0.545)	(0.076)
T5 (30-0.06)	0.404	0.049	0.195	22.729	0.525
	(0.060)	(0.020)	(0.029)	(0.421)	(0.131)
T6 (30-0.06 nF)	0.316	0.166	0.238	24.067	0.400

	(0.320)	(0.285)	(0.265)	(3.403)	(0.498)

Notes: Mean values, standard deviations are given in parentheses.

Our Hypothesis 1 states that the decay of contributions and the group size effect are smaller in an RPG experiment than in a VCM experiment. We first focus on the first part of this hypothesis, Hypothesis 1a. Fig. 2 compares the contributions in the RPG treatments with feedback, T1 (60-Emission) and T2 (30-Emission), with the VCM treatments with feedback, T4 (60-0.06) and T5 (30-0.06), respectively. In T1 (60-Emission) and T2 (30-Emission), we observe remarkably stable contributions over the course of the ten rounds for the respective group sizes of 60 and 30. In T1 (60-Emission), the contributions lie on a nearly horizontal line from rounds 3 to 9, with this holding for rounds 4 to 8 in T2 (30-Emission). In the VCM treatments T4 (60-0.06) and T5 (30-0.06), however, we observe the typical decay of contributions for both group sizes. This pattern appears to support Hypothesis 1a.

In addition, Table 3 compares the contributions during the first part (rounds 1 to 5) and the second part (rounds 6 to 10). In the RPG treatment T1 (60-Emission), contributions do not differ significantly between the two parts (p = 0.263, Wilcoxon test (WT)).[13] In T2 (30-Emission), contributions fall significantly (p = 0.017, WT). The decay from 19.9 percent to 17.5 percent on average is rather small, though. The decay of contributions in the VCM treatments T4 (60-0.06) and T5 (30-0.06) with feedback is significant (both p = 0.012, WT) and much more pronounced in absolute terms. In both treatments, contributions in the second part fall by 50 percent or more. Furthermore, as Table 2 shows, the contributions decrease from 40.4 percent in the first round to 10.3 percent and 4.9 percent in the last round in T4 (60-0.06) and T5 (30-0.06), respectively. Yet, in T1 (60-Emission) and T2 (30-Emission), we find rather similar contributions in the first (26.3 and 25.1 percent) and the last rounds (23.4 and 19.5 percent). Also, a direct comparison of the decays (i.e., the difference between average contributions in the first and second part) between the RPG and VCM treatments with the same group size yields significant differences ($p \leq 0.001$, Mann–Whitney U tests (MWU)). These findings support Hypothesis 1a: the decay of contributions over the course of the experiment is less pronounced in the RPG treatments.

[13] Throughout this section, we provide two-sided p-values. We are always considering group averages, i.e., between 8 and 58 independent observations per treatment (cf. Table 1). We conduct non-parametric tests so that we do not have to rely on the assumption of normally distributed variables.

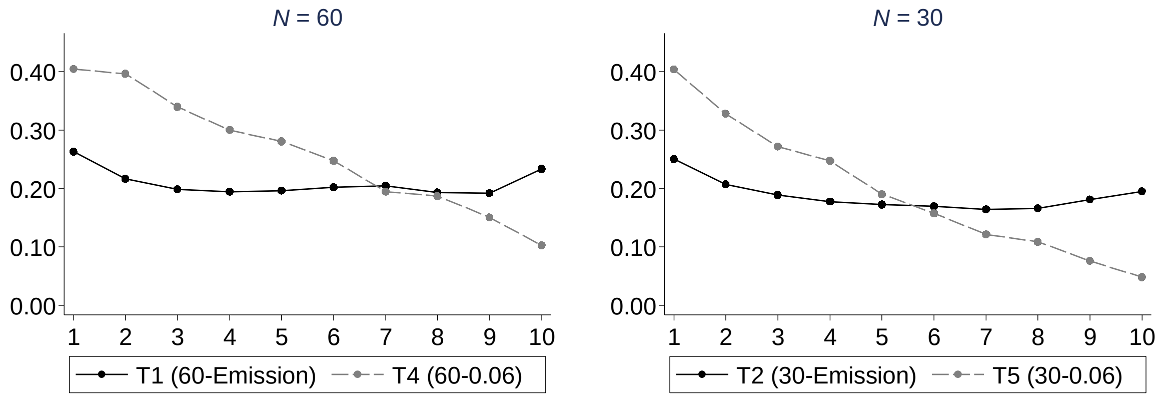

Fig. 2. Mean contributions (as share of the endowment) in T1 (60-Emission), T2 (30-Emission), T4 (60-0.06) and T5 (30-0.06)

Table 3

Comparison of rounds 1 to 5 (part 1) and rounds 6 to 10 (part 2), Wilcoxon Tests.

Treatment	Mean contribution part 1	Mean contribution part 2	p-value (Wilcoxon test)
T1 (60-Emission)	0.214	0.205	0.263
T2 (30-Emission)	0.199	0.175	0.017
T3 (30-Emission nF)	0.259	0.271	0.151
T4 (60-0.06)	0.344	0.177	0.012
T5 (30-0.06)	0.288	0.103	0.012
T6 (30-0.06 nF)	0.271	0.204	0.006

We now turn to the second part of our first hypothesis, which states that we expect a smaller group size effect in the RPG treatments. Our data support Hypothesis 1b: as shown in Table 2, participants in the two RPG treatments with feedback contribute on average 20.9 percent in T1 (60-Emission) and 18.7 percent in T2 (30-Emission). Comparing the two treatments, we find that the difference in contributions is not significant (p = 0.208, MWU). Contributions are, however, significantly larger in the VCM treatment T4 (60-0.06) than in the VCM treatment T5 (30-0.06), where participants on average contribute 26.0 percent and 19.5 percent, respectively (p = 0.006, MWU).

Our Hypothesis 2 relates to the provision of information on payoffs and the other players' behaviour. The first part of this hypothesis, Hypothesis 2a, states that without feedback we expect stable contribution patterns in the VCM and RPG treatments. Fig. 3 compares the contributions in the two feedback treatments T2 (30-Emission) and T5 (30-0.06) to those in the corresponding no-feedback treatments T3 (30-Emission nF) and T6 (30-0.06 nF), respectively. It reveals that the contribution pattern in the RPG treatments is similar. In T3 (30-Emission nF), we observe the same remarkably stable contribution behaviour that we found in the RPG treatments with feedback, T1 (60-Emission) and T2 (30-Emission). The contributions in parts 1 and 2 do not differ significantly in T3 (p = 0.151, see the WT in Table 3). Furthermore, the differences in average contributions that we observe between T2 (30-Emission) and T3 (30-Emission nF) are small and statistically insignificant (p = 0.753, MWU test).

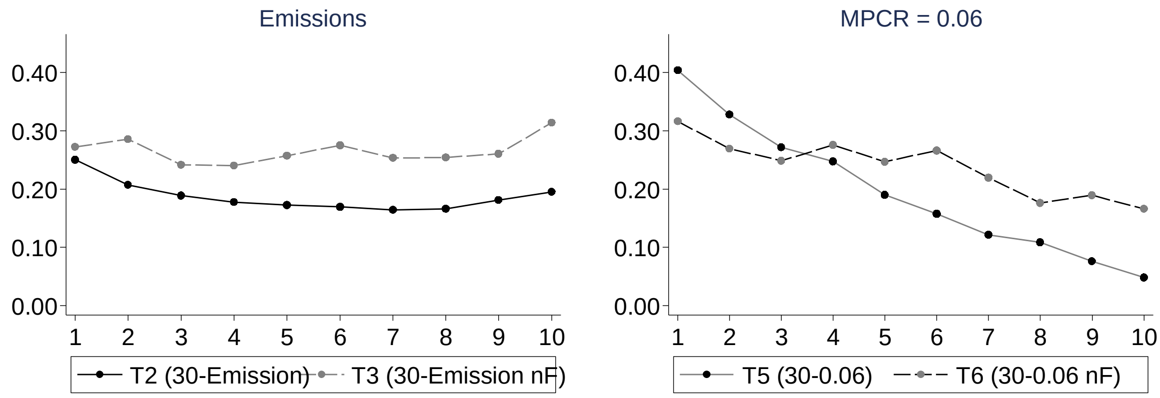

Fig. 3. Average contributions with feedback information (T2 (30-Emission) and T5 (30-0.06)) and without (T3 (30-Emission nF) and T6 (30-0.06 nF))

Regarding the VCM treatments, we observe that in both T5 (30-0.06) and T6 (30-0.06 nF), the average contributions in the first five rounds are larger than those in the last five rounds (p = 0.012 and p = 0.006, respectively, see WT in Table 3). Comparing the decay from part 1 to part 2 in T5 (30-0.06) with that in T6 (30-0.06 nF), we find it to be much stronger with feedback: in the former, contributions drop from 28.8 to 10.3 percent, while in the latter they only decrease from 27.1 to 20.4 percent (p = 0.004, MWU). Receiving feedback on the decreasing average apparently drives the contributions down, while not getting this feedback tends to stabilize contributions. Our findings do not support Hypothesis 2a with respect to the VCM experiments. They do, however, go in the direction described by the hypothesis: the absence of feedback stabilizes the contribution behaviour in the VCM experiments. The decline in contributions in T6 may have different reasons. It cannot be excluded that subjects knew the results of public good experiments and therefore expected that the other participants would reduce their contributions. It may also be that in reality they experienced in small groups that cooperative behaviour is not always stable.[14]

[14] Irlenbusch et al. (2019) observe a similar pattern in an experiment with "intransparent feedback": subjects got feedback but they did not know if the reported number was the lowest, highest or a randomly chosen contribution.

The second part of our second hypothesis, Hypothesis 2b, states that, in RPG treatments with feedback, we expect a drop in contributions from the first to the second round and no significant changes in contributions afterwards. As shown in Figure 2, on the aggregate, we do in fact observe the largest drop in contributions in T1 (60-Emission) and T2 (30-Emission) between the first and the second round. There is no such drop without feedback in T3 (30-Emission nF). Statistical comparisons of potential contribution changes from one round to the next confirm this impression. We find a significant drop between rounds 1 and 2 for T1 (60-Emission) and T2 (30-Emission) (p = 0.012, WT) but not for T3 (30-Emission nF) (p = 0.878, WT). In all three treatments, we also observe a significant drop in contributions between rounds 2 and 3 ($p \leq 0.036$). However, there are no other significant drops in subsequent rounds ($p \geq 0.122$). Thus, we conclude that our data are broadly in line with Hypothesis 2b.

5.2 Regression analysis

We also run a random-effects linear regression to test our hypotheses. We first focus on Hypothesis 1 and therefore do not consider the treatments without feedback. Let b_{it} denote the contribution of player *i* in *Round t* of the game. In order to compare the decay of contributions between RPG and VCM treatments, we model the contribution as a linear function of *Round t* and its interaction with the treatment characteristics as follows

$$b_{it} = \beta_0 + \beta_1 \cdot Round\ t_t + \beta_2 \cdot RPG_i + \beta_3 \cdot Round\ t_t \cdot RPG_i + \beta_4 \cdot Group\ Size\ 60_i + \beta_5 \cdot Round\ t_t \cdot Group\ Size\ 60_i + \beta_6 \cdot RPG_i \cdot Group\ Size\ 60_i + \beta_7 \cdot Round\ t_t \cdot RPG_i \cdot Group\ Size\ 60_i + \beta_8' \cdot x_i + \eta_i + \varepsilon_{it}.$$

The dummy variable RPG_i indicates the RPG treatments while the dummy variable *Group Size 60* indicates the treatments with a group size of 60. Controls for gender, location, and age are included in x_i. We assume independent and normally distributed error terms denoted by η_i and ε_{it} that capture differences between individuals and idiosyncratic effects within rounds, respectively.

The estimated coefficients are presented in Table 4. We present three models: With respect to our treatments, the first model only conditions on RPG versus VCM, the second only on group size, while the third includes the full set of interactions. As shown in column (1), contributions decrease by 3.5 percentage points per round in the VCM treatments overall ($p < 0.001$). The term *Round t · RPG* allows us to compare the decay in the VCM treatments to the decay in the RPG treatments, providing us with another test of Hypothesis 1a. This hypothesis states that we expect a smaller decay with the real public good. In line with Hypothesis 1a, the estimation indicates that overall the decay is 3.1 percentage points smaller in RPG treatments ($p < 0.001$), respectively.

Table 4

Random-effects regressions

	(1)	(2)	(3)
Round t	-0.035***	-0.021***	-0.037***
	(0.002)	(0.004)	(0.003)
RPG	-0.209***		-0.186***
	(0.019)		(0.025)
Round t · RPG	0.031***		0.032***
	(0.002)		(0.003)
Group size 60		0.028	0.045
		(0.040)	(0.032)
Round t · Group Size 60		0.003	0.004
		(0.006)	(0.003)
RPG · Group Size 60			-0.034
			(0.034)
Round t · RPG · Group Size 60			-0.001
			(0.004)
Constant	0.524***	0.417***	0.496***
	(0.048)	(0.048)	(0.046)
Overall R-squared	0.093	0.064	0.102
Observations	14,400	14,400	14,400
Number of subjects	1,440	1,440	1,440

Notes: This table reports coefficients on the observed contributions. Regressions also include controls for age, gender, and location. Standard errors clustered on the session level are given in parentheses. * p<0.10, ** p<0.05, *** p<0.01 (two-sided).

In order to investigate the group size effect, we first consider the model in column (2). The coefficients of the group size dummy *Group Size 60* and its interaction with the round *Round t · Group Size 60* are insignificant when jointly considering RPG and VCM treatments ($p \geq 0.481$). The group size effect refers to the overall contributions of groups. Thus, it may influence the intercept as well as the slope of the estimated contributions. A joint test of both coefficients shows that they are significantly different from zero ($p < 0.001$). Thus, there is evidence for a group size effect. Yet, Hypothesis 1b states that the group size effect will be larger for VCM than for RPG treatments. The model in column (3) does not support this view: the intercept is not significantly different as indicated by *RPG · Group Size 60* ($p = 0.319$), nor are the slopes as indicated by *Round t · RPG · Group Size 60* ($p = 0.718$). Also, jointly both coefficients do not differ significantly from zero ($p = 0.124$).

We test our Hypothesis 2 with another set of regressions. For each treatment with a group size of 30, we apply the following model specification:

$$b_{it} = \beta_0 + \beta_1 \cdot I(Round\ t{=}1) + \beta_2 \cdot I(Round\ t{=}3) + \ldots + \beta_9 \cdot I(Round\ t{=}10) + \beta_{10}' \cdot x_i + \eta_i + \varepsilon_{it}.$$

We focus on one treatment at a time and replace the variable *Round t* with a dummy for each round. The baseline category for the dummies in our specification is round 2 (in order to provide a straightforward test of Hypothesis 2b). The regression results for the four treatments with 30 subjects per group are shown in Table 5

Hypothesis 2a states that there will be no significant changes in contributions over the 10 rounds in treatments without feedback. Strictly speaking, this hypothesis is rejected by the results in Table 5. Columns (2) and (4) present the regression results for the respective treatments. They reveal that contributions in several rounds differ significantly from the contributions made in the second round (our baseline category). However, the regressions also support the impression from the previous section. There is no systematic decay of contributions relative to round 2 in the RPG treatments, as shown in columns (1) and (2). In the first round of the RPG treatment with feedback, they are 4.4 percentage points higher than in round 2. In the last round, they are 1.2 percentage points lower. Without feedback, contributions are 1.4 percentage points lower initially and 2.8 percentage points above round 2 in the last round. The comparison of columns (3) and (4) highlights that the decay in contributions in the VCM treatments is much more pronounced with feedback than without. Without feedback, the coefficients indicate a change in contributions between 4.7 percentage points in the first round and -10.3 percentage points in the last round relative to round 2. With feedback, these values range from 7.7 to -27.9 percentage points.

The results in column (1) of Table 5 allow us to also test Hypothesis 2b, which states that contributions in treatment T2 (30-Emission) should only drop between rounds 1 and 2. Estimated contributions are 4.4 percentage points higher in the first round than in the second round ($p < 0.001$), providing partial support for Hypothesis 2b. As pointed out above, there is, however, another significant drop after the second round. In round 3, contributions are 1.8 percentage points lower than in the second round ($p = 0.010$). The subsequent changes in contributions are relatively small. Figure 4 plots the corresponding estimates of the round dummies for T2 (30-Emission) together with their 95% confidence intervals. In addition, we conduct Wald tests comparing the round dummies starting in $t = 3$ with each other. Without correcting for multiple tests, they suggest that contributions in round 3 are lower than those in rounds 5 to 8 ($p \leq 0.039$) and that round 10 contributions are larger than those in rounds 6 to 8 ($p \leq 0.031$). Yet, none of the other comparisons is significant ($p \geq 0.104$). Thus, we again conclude that our results are broadly in line with Hypothesis 2b.

Table 5

Random-effects regressions: contributions over time.

	(1) T2 (30-Emission)	(2) T3 (30-Emission nF)	(3) T5 (30-0.06)	(4) T6 (30-0.06 nF)
Round t = 1	0.044***	-0.014	0.077***	0.047
	(0.009)	(0.020)	(0.014)	(0.059)
Round t = 3	-0.018***	-0.044**	-0.056***	-0.021
	(0.007)	(0.018)	(0.010)	(0.030)
Round t = 4	-0.030***	-0.045	-0.080***	0.006
	(0.009)	(0.032)	(0.020)	(0.044)
Round t = 5	-0.035***	-0.029	-0.137***	-0.022
	(0.009)	(0.030)	(0.028)	(0.029)
Round t = 6	-0.038***	-0.010	-0.170***	-0.003
	(0.010)	(0.027)	(0.030)	(0.046)
Round t = 7	-0.043***	-0.032	-0.206***	-0.050*
	(0.009)	(0.020)	(0.023)	(0.030)
Round t = 8	-0.041***	-0.031	-0.219***	-0.093**
	(0.012)	(0.023)	(0.024)	(0.043)
Round t = 9	-0.026*	-0.025	-0.251***	-0.080*
	(0.014)	(0.030)	(0.023)	(0.042)
Round t = 10	-0.012	0.028	-0.279***	-0.103**
	(0.016)	(0.035)	(0.024)	(0.052)
Constant	0.329**	0.871***	0.281***	-0.348
	(0.134)	(0.208)	(0.100)	(0.518)
Overall R-squared	0.050	0.094	0.216	0.119
Observations	2,400	580	2,400	300
Number of subjects	240	58	240	30

Notes: This table reports coefficients on the observed contributions with round 2 as the baseline category. Regressions also include controls for age, gender, and location. Standard errors are given in parentheses. They are clustered on the session level for the treatments with feedback. For the treatments without feedback, robust standard errors are given. * $p<0.10$, ** $p<0.05$, *** $p<0.01$ (two-sided).

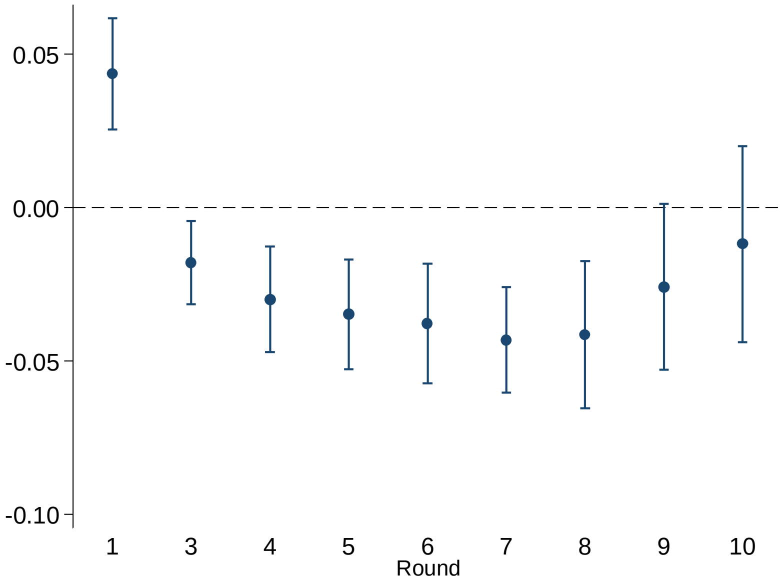

Fig. 4. Estimated round dummies and their 95% confidence intervals for T2 (30-Emission)

6. Discussion and Conclusion

The ultimate goal of experimentally analysing the private provision of public goods is directed at increasing the understanding of how real cooperation problems are solved by large groups. This requires knowledge of the mechanisms that influence the contribution behaviour of members of large groups. Experimental research using the VCM has shown that cooperation erodes because these mechanisms cause contributions to the production of the public good to fall over time. Our results have shown that this is not the case when the public good in the VCM is replaced by a real public good, which in our case is emission reduction. At first glance, this could be interpreted as an indication that the external validity of the VCM experiments is rather limited. However, this would be a premature conclusion. Based on the results of laboratory research on the VCM, we predicted a constant contribution level in the case of a real public good, which was supported by our data.

Our observation that group size in the laboratory does not matter for the contributions laboratory subjects make to a real global public good suggests that one can study real public good provision using very small group sizes in the laboratory. As such, our findings contribute to experimental research on public good provision also from a methodological point of view.

Nevertheless, the results presented here raise new questions. If we are correct in our interpretation that both the salience of the mutual benefits of real public goods as well as the dynamics of their provision (Fischbacher and Gächter, 2010) are determined outside the laboratory (i.e., not by the conditions and people in the lab), then the first question is: What does the salience of a real public good problem depend on? Weimann et al. (2019) demonstrate that in a VCM experiment, the salience is determined by the group size and the MPCR. But what are their determinants in the real world? How are these values perceived by people providing real public goods? Economists know very little about that. To gain deeper insights, international comparative studies would probably be necessary, for example, to investigate whether the cooperation benefits that arise from climate protection are perceived differently in different countries and why this is the case. A study in this direction is Grimalda et al. (2022), who run an intra- and international interactive online collective-risk social dilemma experiment with German and Russian students in groups of six. They find that Russian subjects contribute significantly less than German students in the national treatments, but adapt to the high German contribution standards in the international sessions – in particular, when punishment is possible.

A central element in explaining the difference between the dynamics of contributions made in the VCM treatments and those in the real public good treatments is that, with regard to the provision of the real public good, the behaviour of *all* people involved (who are mostly outside the lab) is constant from the perspective of an individual participant in the experiment. This raises the question of whether the explanation developed by Fischbacher and Gächter (2010) for VCM experiments can also be applied to real public goods. Given our results, we argue that this depends primarily on how well the contributions of *all* the "others" can be observed. If we can only observe contributions made by a small subsample, the long-term dynamics are not influenced by this information. However, if information about the average behaviour of all people is available (as is the case in VCM experiments), this might affect the dynamics of contributions. For instance, if appropriate media coverage creates the impression that the general efforts to protect the climate are not diminishing, cooperation should be stabilized. Our experiment suggests that information about the necessity of cooperation and information about the behaviour of all *other* people involved in the cooperation task are both important for the provision of real public goods.

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Acknowledgements

We thank Christian Stahr for his valuable research assistance and Christoph Helbach, Andreas Markstädter, Martin Schmidt, and Jan Siebert for their support in running the experiments. We are grateful for the helpful comments we received at various conferences, workshops and seminar presentations. We thank Axel Ockenfels, Bettina Rockenbach, Karim Sadrieh, and Reinhard Selten for helpful suggestions.

Online Appendix to

"CO_2 Emission Reduction – Real public good provision by large groups in the laboratory"

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[$)]Financial support by the Deutsche Forschungsgemeinschaft is gratefully acknowledged.

Appendices

Appendix A: Characteristics of the VCM

A.1: Individual payoff function of the VCM and the interplay between group size and MPCR

In the following, we describe the individual payoff function of the VCM in order to point out the specific relationship between the marginal per capita return (MPCR) and the number of group members (*N*) that is implied by this function.

Let z_i denote the initial endowment of group member i, b_i the individual contribution to the provision of the public good, and α the return every group member receives if one monetary unit is invested in the production of the public good. The marginal return on the share of z_i that is not invested in the public good is normalized to 1. Then α is identical to the MPCR of investments in the public good. The group member i's payoff π_i is

$$\pi_i = (z_i - b_i) + \alpha \sum_{j=1}^{N} b_j \,. \qquad [1]$$

A cooperation problem arises if the following holds:

$$\alpha < 1; N\alpha > 1 \text{ and, thus, } \alpha > {}^{1}/_{N} \,. \qquad [1^*]$$

Since $\alpha < 1$, not investing in the public good is more profitable than investing from the individual's point of view. However, since $\alpha > 1/N$, investing is efficient from the group perspective. Condition 1* reveals that only for large *N* can the MPCR become very small. Consequently, cooperation problems that involve very small MPCRs can only be studied in large groups.

A.2: Salience of cooperation benefits and MPCR-distance

The conjecture that the interplay of group size and MPCR is decisive for cooperation in public good experiments has been already brought up by Isaac and Walker (1988), Isaac et al. (1984), and Isaac et al. (1994). The latter stated that behaviour in public good games "is influenced by a subtle interaction between group size and MPCR rather than simply the sheer magnitude of either" (p. 32). Davis and Holt (1993) and Isaac et al. (1994) introduced the Minimal Profitable Coalition (MPC) and the maximal advantage an efficient solution has over the Nash outcome, respectively, as explaining factors for cooperation in the public good.

Based on a systematic analysis of different combinations of group size and MPCRs (see Figure A.1), Weimann et al. (2019) developed the MPCR-distance hypothesis, which is based on the idea that people confronted with a social dilemma, can only be expected to cooperate if group members are aware that it is to everyone's advantage if everyone cooperates. That means the mutual benefits of cooperation should be *salient* to the members of the group. Consequently, the more salient the advantage of cooperation, the more subjects can be confident that the group members have understood the social dilemma they are in and behave cooperatively. The

MPCR-distance $d = MPCR - 1/N$ includes the two parameters *MPCR* and $1/N$ of the payoff function, which all subjects are informed about. As long as $MPCR < 1/N$, investments in the public good are inefficient. If $1 > MPCR > 1/N$, the overall efficiency gains from an investment in the public good increases (for a given *N*) in *MPCR*. Thus, given the salience assumption, the higher the MPCR-distance *d*, the more salient is the fact that cooperation is mutually beneficial.

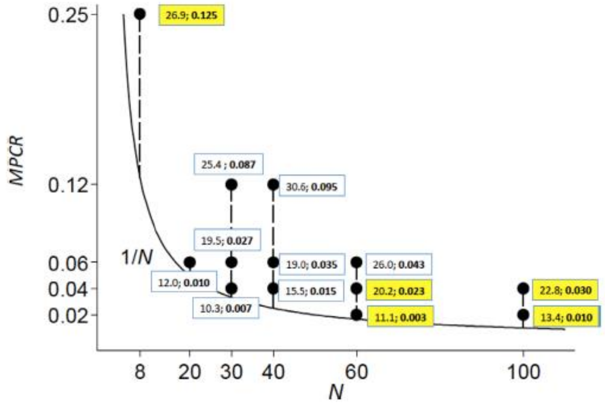

Fig. 5. *MPCR, N*, average contributions, and *MPCR*-distances of all 13 connected-lab treatments.
Note: Each dot in the graph represents one *N-MPCR* combination. It also shows the 1/*N* curve. The first numbers in the labels are the percentages of average contributions for each treatment, the second numbers in bold are the respective *MPCR*-distances *d*. White labels mark additional treatments, yellow labels mark those analyzed in Section 2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. A.1: *The Interplay between MPCR, N, and Average Contributions*
Source: Weimann et al. (2019, Figure 5, p. 357)

To develop an intuition for their hypothesis, Weimann et al. (2019) suggest thinking of $1/N$ not only as the minimal MPCR for a public good experiment, but also as a value that informs the group members about their relative weight in the group. The MPCR-distance therefore is a measure for the difference between the MPCR – the amount a group member receives from investing one euro cent into the public good – and the relative weight the respective group member has in the group with regard to group size ($1/N$). If the MPCR is much bigger than $1/N$, i.e., *d* is large, then the gains from cooperation are much higher than the impact the relative weight of the group member has and, thus, the more salient is the advantageousness of cooperative behaviour to the subject. On the contrary, when *d* is small, the gains from cooperation do not appear to outweigh the relative impact the group member has on the group and, thus, cooperation declines.

Weimann et al. (2019) provide evidence that the MPCR-distance has high explanatory power. Although the MPCR-distance hypothesis and the MPC-model of Davis and Holt (1993) predict the same ordering of contributions, the models using the MPCR-distance in most of the regressions outperform the model using MPC.

Appendix B: Instructions

B.1: Instructions T1(60-0.06) RPG

Instructions 60-Emission Rights

<u>*Preliminary remarks*</u>: You are participating in a study of decision-making in the context of experimental economics research. While participating in the experiment, you have to take a series of decisions. It is important to note that the consequences presented in the instructions are real in the experiment. That is, you will make decisions about real monetary payoffs.

Since you are making decisions about real consequences, it is important for you to understand what the consequences of each choice option are during the experiment. If you are uncertain or do not understand the description of the experimental procedure, please contact the experimenter at any time. We will then come to your cubicle.

<u>*Experiment*</u>: During the experiment, you have to take a sequence of decisions. You will earn money. How much money you will earn will depend on your decisions. Your total earnings will be paid in cash at the end of the experiment. Both your decisions and your payoff are confidential, i.e. no other participant will receive this information.

You are part of a group of 60 participants. These 60 people are located in four experimental laboratories across Germany, connected via the Internet. All group members have received the same instructions. Moreover, the laboratories are connected via a video connection. If you have any doubts about this procedure, please take a look at our live video conference!

You and the other 59 group members are facing the following identical decision situation during 10 consecutive rounds: In each round, you receive an endowment of 120 euro cents. You decide how much of this endowment you want to "keep", and how much you want to "contribute". That part of your endowment that you **do not contribute** (i. e. that you "keep"), you keep for yourself.

The **total amount of the contributions** of all 60 participants will be used to buy ***CO_2 emission rights.***

An emission right (for one ton of CO_2) currently costs about 7 euros. This means that approximately 1.43 kilograms of CO_2 can be bought for every euro cent contributed. The rights bought will be decommissioned, resulting in a reduction of CO_2 emissions to the extent of the rights bought. To find out what these rights cover and why their decommissioning leads to a reduction in emissions, please see the following overview.

How emissions trading works

Step 1

The EU determines which companies are subject to emissions trading:

a. Energy companies
b. Aluminium smelters
c. Lime plants
d. Cement manufacturers
e. and many more.

} Summing up to about 60% of CO_2-emissions in Germany

Step 2

- The EU determines how much CO_2 may be emitted in total by all these companies.
- This upper limit for the total amount of emissions is termed *CAP*.
- For each ton of CO_2 within the CAP, an emission right is created.
- These rights are distributed to the emitters in Europe (auctioned off or made available free of charge).

Step 3

- Companies may only emit CO_2 if they are holding a corresponding emission right.

Step 4

- The companies may buy and sell emission rights.
- The rights are traded via an electronic exchange.

Effects

- The total quantity of the emissions is limited by the CAP only.
- If someone buys emission rights at the exchange and decommissions them (i.e. neither sells nor uses the rights), this corresponds to lowering the CAP by the corresponding amount.
- The rights bought and decommissioned are permanently withdrawn from the emitters.
- Therefore, the CO_2 emission decreases.

Notes

- Buying an emission right *actually* saves CO_2.
- One emission right (for one ton of CO_2) currently costs about €7.
- The annual per capita emission in Germany is about 12 tons.

Please note that your contribution per round can be any amount between 0 and 120 euro cents and that all group members are facing an identical decision situation in all 10 rounds. After each round, you will be informed of the amount you kept, your contribution, the average contribution of *all* 60 group members, your payoff based on the contributions of all group members, your payoff in the respective round, and your payoff cumulated over all periods. In addition, we will inform you about the amount of CO_2 that “has already been decommissioned” by the contributions. Moreover, you will see a table listing the same information for all previous rounds.

Practice rounds: Before starting with the experiment, you have the opportunity to decide in three practice rounds. In these practice periods, the average contribution of all other group members will be *given* as it is randomly generated. Furthermore, your own contribution will be preset, too. Your task is to calculate the earnings in the respective round yourself. To this end, we will provide you with a calculator, paper, and pencil. After entering your solution in the respective box, please click on the “Solution” button. You will then be informed whether your answer is right or wrong. Also, the calculation method will be shown. If you have any questions during the practice rounds, please raise your hand. Right after the practice periods are over, the experiment will start automatically

Payoff: Please stay in your cubicle after all 10 rounds have ended. You will be called individually by the experimenter to receive your payoff. Please hand in your participation number (which you drew at the beginning of the experiment), then enter your name in readable handwriting in the list we will present to you and acknowledge receipt of the payment with your signature. Please leave the laboratory after receiving your money.

On completion of the series of experiments (a total of 8 sessions), the aggregated contributions are used to decommission CO_2 certificates (see Statement of Commitment to Buying Emission Rights). Since the administrative effort is rather high, there will be a delay in informing you. Therefore, the certificate of CO_2 emission rights bought and decommissioned will be made available in the laboratory's information box and on the Internet at http://…… [Note: this is different for each laboratory]. In addition, the certification of decommissioning will be sent to all participants by mail.

The Statement of Commitment at your cubicle is meant for you to take home.

Finally, we would like to ask you not to talk to anybody about the content of this experiment to avoid influencing future participants. Thank you for your cooperation!

B.2: Instructions T4 (60-0.06) VCM

Preliminary: You are participating in an economic experiment focusing on decision-making. If there are still some questions after having read these instructions or during the experiment, please raise your hand. We will then come to your cubicle.

While participating in the experiment, you have to take a sequence of decisions. You will earn money. However, how much money you will earn will depend both on your decision and the decisions of the other participants. Your total earnings will be paid in cash at the end of the experiment. Both your decisions and your payoff are confidential, i.e. no other participant will receive this information.

You are part of a group of 60 participants. These 60 people are located in four experimental laboratories across Germany, connected via the Internet. All group members have received the same instructions. Moreover, the laboratories are connected via a video connection. If you have any doubts about this procedure, please take a look at our video conference!

You and the other 59 group members are facing the following identical decision situation during 10 consecutive rounds: In each round, you receive an endowment of 120 euro cents. You decide how much of this endowment you want to "keep", and how much you want to "contribute". Each contribution x creates an amount 0.06 x for *each* group member (including the contributor). That means that for every euro cent you contribute, the whole group will be paid 3.60 euro cents ($0.06 \cdot x \cdot 60$). For each euro cent you contribute, you will be paid 0.06 euro cents, like all other group members. That part of your endowment that you do not contribute (i. e. that you "keep"), you keep for yourself.

Summing up in one formula, your earnings in euro cents per round are as follows:

120 – your contribution + 0.06 · (sum of all group members' contributions)

Please note that your contribution per round can be any amount between 0 and 120 euro cents and that all group members are facing an identical decision situation. After each round, you will be informed of the amount you kept, your contribution, the average contribution of *all* 60 group members, your payoff based on the contributions of all group members, your payoff in the respective round, and your payoff cumulated over all periods. Moreover, you will see a table listing the same information for all previous rounds.

Practice rounds: Before starting with the experiment, you have the opportunity to decide in three practice rounds. In these practice periods, the average contribution of all other group members will be *given* as it is randomly generated. Furthermore, your own contribution will be preset, too. Your task is to calculate the earnings in the respective round yourself. To this end, we will provide you with a calculator, paper, and pencil. After entering your solution in the respective box, please click on the "Solution" button. You will then be informed whether your answer is right or wrong. Also, the calculation method will be shown. If you have any questions during the practice rounds, please raise your hand. Right after the practice periods are over, the experiment will start automatically.

Payoff: Please stay in your cubicle after all 10 rounds have ended. You will be called individually to receive your payoff. Please hand in your participation number (which you drew at the beginning of the experiment) and enter your name and signature in the payment list. Please leave the laboratory after receiving your money.

Finally, we would like to ask you to not talk to anybody about the content of this experiment to avoid influencing future participants. Thank you for your cooperation!

Appendix C: Statement of Commitment to Buying Emission Rights

I, Professor Dr. Joachim Weimann, in my capacity as scientific director of the project, hereby confirm that the amount raised by the participants will be used exclusively and without deduction for buying and decommissioning emission rights. The purchase will be handled by the German Environment Agency and the DEHSt (German Emissions Trading Authority). The certification of decommissioning will be sent to all participants by mail after completing the experiments. In addition, the certificate will be made available in the laboratory's information box and on the Internet at http://maxlab.ovgu.de/zertifikate.

Professor Dr. Joachim Weimann

[Note: The declaration was modified regarding names and functions of the scientific coordinators in the other three participating labs.]

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Kaufverpflichtungserklärung

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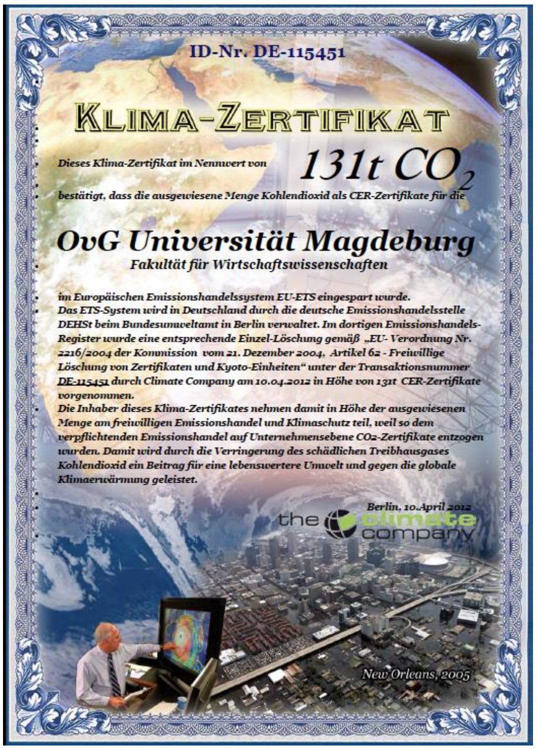
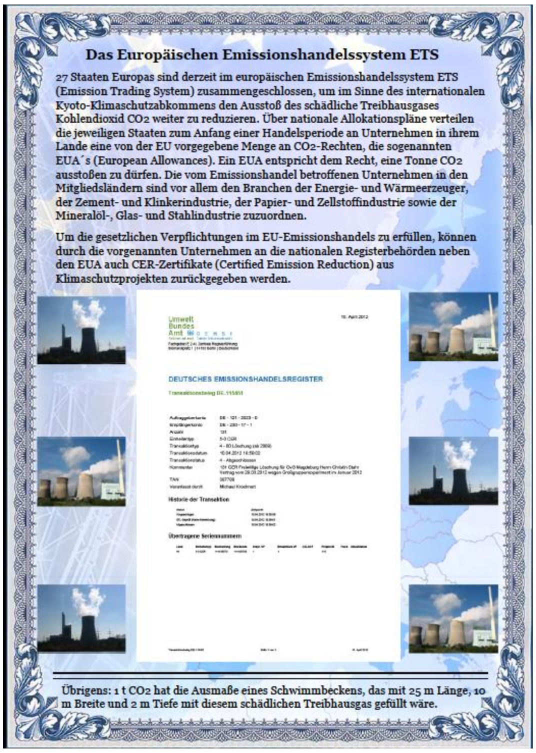
Hiermit versichere ich, Professor Dr. Joachim Weimann, in der Funktion als wissenschaftlicher Leiter des Projektes, den durch die Teilnehmer erspielten Betrag ohne Abzug und ausschließlich für den Kauf und die Stilllegung von Emissionsrechten zu verwenden. Der Kauf wird über das Umweltbundesamt und die DEHSt abgewickelt. Der Nachweis zur Stilllegung wird nach Abschluss der Experimente per Mail an alle Teilnehmer verschickt. Zusätzlich wird der Nachweis im Schaukasten des Labors, sowie im Internet unter http://maxlab.ovgu.de/zertifikate bereitgestellt.

Prof. Dr. Joachim Weimann

Appendix D: Certificate of decommissioning CO_2 emission rights





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