unibz
Fakultät für Wirtschaftswissenschaften
Facoltà di Economia
Faculty of Economics and Management

BEMPS –
Bozen Economics & Management
Paper Series

NO 96/ 2022

Collective minimum contributions to counteract the ratchet effect in the voluntary provision of public goods

Marius Alt, Carlo Gallier,
Martin Kesternich, Bodo Sturm

Collective minimum contributions to counteract the ratchet effect in the voluntary provision of public goods

Marius Alt, Carlo Gallier, Martin Kesternich, and Bodo Sturm

This version: November, 2022

Abstract: We experimentally test a theoretically promising amendment to the ratchet-up mechanism of the Paris Agreement. The ratchet-up mechanism prescribes that parties' commitments to the global response to climate change cannot decrease over time and our results confirm that its effect is detrimental. We design a public goods game to study whether an amendment to the mechanism that stipulates all agents to contribute at least a collective minimum to the public good which is based on the principle of the lowest common denominator promotes cooperation. We find that binding collective minimum contributions improve the effectiveness of the ratchet-up mechanism. Non-binding minimum contributions, in contrast, do not foster cooperation. Our data reveal conditional cooperative dynamics to explain the difference. If other participants contribute less than the collective minimum contributions, even initially cooperative participants start to negatively reciprocate such a form of non-compliance by contributing less.

Keywords: global public goods, climate change, institutions, ratchet-up mechanism, minimum contributions, laboratory experiment

JEL: C72, C92, H41

Acknowledgement: Marius Alt is at the European Commission's Joint Research Centre in Ispra (Marius.ALT@ec.europa.eu). Carlo Gallier is at the Free University of Bozen-Bolzano and ZEW – Leibniz Centre for European Economic Research (Carlo.Gallier@unibz.it). Martin Kesternich is at ZEW – Leibniz Centre for European Economic Research and at the University of Kassel (martin.kesternich@zew.de). Bodo Sturm is at Leipzig University of Applied Sciences (HTWK Leipzig) and ZEW – Leibniz Centre for European Economic Research (bodo.sturm@htwk-leipzig.de). We are grateful for helpful insights from conference and seminar participants at the 7th workshop on Experimental Economics for the Environment, the Euregio Economics Meeting 2022, the 2022 European Meeting of the Economic Science Association, as well as the 2021 and 2022 Meeting of the German Association for Experimental Economic Research. We thank the German Federal Ministry of Education and Research for financial support under Grant FKZ 01LA1825A/C. All authors declare that they have no financial interest or other conflicts of interest.

Correspondence: Carlo Gallier, Free University of Bozen-Bolzano, Italy: Carlo.Gallier@unibz.it.

1. Introduction

The centerpieces of the Paris Agreement on climate change are parties' individually chosen Nationally Determined Contributions (NDCs), i.e., their self-determined commitments for greenhouse gas mitigation actions. This *bottom-up* structure of the agreement certainly facilitated the entry-into force of the treaty in 2016 only one year after its adoption at the 21st United Nations Climate Change Convention (COP21) in Paris. However, it also engendered initial commitments to clearly fell short of achieving the agreement's long-term climate objective. Consequently, parties' commitments require strong progressions to limit global warming well below 2°C (e.g., Rogelj et al. 2016).

To address this challenge, the Paris Agreement includes a mechanism that aims to gradually increase parties' commitments over time and thus achieve the long-term target: the ratchet-up mechanism. The agreement stipulates parties to regularly update and renew their NDCs and to take stock of the commitments every five years to assess the collective progress towards the 2°C target (UNFCCC 2015, Article 4). To ensure that parties' commitments show sufficient progression over time, the ratchet-up mechanism prescribes that "[…] *Party's successive nationally determined contribution will represent a progression beyond the Party's then current nationally determined contribution* […]" (UNFCCC 2015, Article 4.3).

However, the debates accompanying the COP26 meeting in Glasgow in 2021 raise serious doubts regarding the effectiveness of the ratchet-up mechanism. Even though some of the newly submitted commitments for 2030 show progress, more than half of the updated NDCs do not meet the ratcheting requirement. In total, parties' commitments are still not sufficient to achieve the 2°C target (UNEP 2021). To study the ratchet-up mechanism in a controlled environment, Gallier and Sturm (2021) took it to the laboratory and provide evidence that it performs poorly in a public goods experiment. They report a clear ratchet effect: Participants who know that their contributions to the public good cannot decrease or even have to increase over time strategically restrict their contributions at the beginning of the game. They do so because they anticipate that higher contributions would rise future obligations and, thus, increase their risk of being free-ridden by players with less ambitious contributions. Overall, the results show that the mechanism leads to lower contributions than a conventional voluntary contribution mechanism. All this suggests that the ratchet-up mechanism in its current form does not promote cooperation. An amendment is clearly needed to counteract the ratchet effect by preventing the mechanism from further increasing the risk of being free-ridden by others and thus creating incentives to strategically restrict contributions.

Collective minimum contributions are a natural candidate for such an amendment. Based on the principle of the *lowest common denominator* (e.g., Orzen 2008) they combine two important properties. First, they can complement the ratchet-up mechanism and – theoretically – counteract the ratchet effect by reducing the risk of being free-ridden and thus promoting cooperation. Second, they could be practically feasible, because they preserve certain aspects of parties' (national) sovereignty. More precisely, a collective minimum contribution mechanism requires all parties to submit a commitment and to contribute at least the lowest commitment proposed. Thus, each party retains sovereign because it cannot be obliged to contribute more than initially desired. Furthermore, if parties agree to contribute at least the lowest common denominator of all proposed commitments, each party has a weakly dominant strategy to propose contributions at the socially efficient level.[1]

We report a laboratory public goods game with a ratchet-up mechanism, that prescribes that contributions cannot decrease over time, to study different collective minimum contribution mechanisms of varying stringency in a controlled environment. We test whether such mechanisms can counteract the ratchet effect and thus improve the performance of the ratchet-up mechanism.[2] Laboratory experiments are a useful tool for investigating alternative amendments to the mechanism. Outside of the laboratory, it is difficult to find appropriate counterfactuals, making other empirical evaluations challenging. In addition, comparing experimental data with predictions allows us to empirically evaluate the insights arising from our theoretical considerations. Finally, experimentation allows for random assignment of treatments, which permits unambiguous causal inference.

Implementing collective minimum contribution mechanisms into the game requires two stages: Agents first play the collective choice stage and then the contribution stage. In the collective choice stage, agents agree upon a minimum contribution level. Based on the principle of the lowest

[1] Technically, we assume that all parties comply with the binding lowest common denominator of all proposed commitments. In this respect, collective minimum contributions do not necessarily have to meet the requirements of a self-enforcing agreement (e.g., Barrett 1994) to affect equilibrium behavior.

[2] Gallier and Sturm (2021) distinguish between strong ratcheting and weak ratcheting. While in strong ratcheting individual contributions have to be strictly higher than contributions in the previous period, in weak ratcheting individual contributions only have to be at least as high as contributions in the previous period. Since the results of both ratcheting mechanisms are very similar and weak ratcheting is theoretically easier to handle, we use weak ratcheting only.

common denominator, all agents must propose an individual minimum contribution level to the public good. The minimum of all proposals determines the lower bound of agents' public good contribution levels in the first period of the contribution stage. From the second period of the contribution stage onwards, ratcheting applies, and agents' public good contributions must be at least as high as in the period before.

We test two collective minimum contribution mechanisms of varying stringency, i.e., we vary whether the minimum contribution levels are enforceable. If the mechanism is strict, the collective minimum contributions are enforceable and binding, such that agents are bound to contribute at least the minimum contribution level at the beginning of the contribution stage. In this case, agents have a weakly dominant strategy to propose and contribute the socially optimal public good provision level. Although binding minimum contribution levels are hardly implementable in multilateral interactions of sovereign parties, they serve as an important benchmark for the mechanism's effectiveness. In contrast, if the mechanism is not enforceable, the collective minimum contribution levels remain non-binding. Although this version of the mechanism is comparatively easy to implement even outside of the laboratory, the collective minimum contributions remain *numerical cheap talk*. Thus, they have no bearing on theoretical predictions of agents' public good provision levels – at least if we assume that agents are rational and purely self-interested. Behavioral research, however, reveals that even non-binding numerical commitments could serve as a commitment and coordination device and promote cooperation (e.g., Bochet and Putterman 2009, Koessler 2022).

Although we are not aware of any other research that designs and tests amendments to the ratchet-up mechanism of the Paris Agreement, there are important and strongly related contributions of laboratory experiments to environmental and climate policy.[3] For instance, Cason (1995) and Cason and Plott (1996) provide early examples. They use laboratory experiments to study the design of formal governmental interventions like markets for tradeable emission permits to control nationwide sulfur dioxide pollution. More recently, Cason et al. (forthcoming) test how price floors in tradeable emission markets affect firms' incentives to invest in abatement technologies. Our paper, in contrast, is motivated by negotiations on climate change mitigation where a lack of enforcement capacities is a fundamental problem that further hinders international cooperation (e.g., Barrett 1994). This gives rise to a growing literature on how to design international climate

[3] See, e.g., Sturm and Weimann (2006) and Noussair and van Soest (2014) for selective surveys of experimentation in environmental and resource economics.

negotiations, in particular, applied to the Paris Agreement. For instance, Schmidt and Ockenfels (2021) find that negotiating a uniform common commitment, such as a minimum carbon price, could be more successful in achieving international cooperation instead of negotiating individual commitments. Barrett and Dannenberg (2022) consider linking trade agreements to international climate negotiations. They find that especially multilateral linkage could promote cooperation. In addition, Barrett and Dannenberg (2016) investigate the effect of the pledge and review procedure embedded in the Paris Agreement and conclude that the pledge and review process could lead to a small increase in contributions. Relatedly, Orzen (2008) shows that pledges can promote cooperation substantially, if the lowest pledge per group determines a binding lower bound for all group members. Following this approach, other experimental results reveal that minimum contributions schemes based on the principle of the lowest common denominator can increase cooperation. This holds in particular, if the minimum contributions apply to all participants and not only to a subset that has voluntarily agreed to comply (Dannenberg et al. 2014) and if existing heterogeneities are addressed by re-distributing the costs of providing the public good (Kesternich et al. 2014; Gallier et al. 2017).

Our experiment yields three main findings. First, we endorse that the ratchet-up mechanism leads to significantly lower cooperation than a voluntary contribution mechanism. Second, we find that a binding collective minimum contribution mechanism counteracts the ratchet effect. Thus, in line with our theoretical considerations, binding collective minimum contributions significantly increase participants' contributions to the public good. Overall, the cooperation rate increases by about 25 percentage points compared to the treatment with a ratchet-up mechanism but without minimum contributions. Third, a non-binding minimum contribution mechanism, in contrast, does not increase participants' public good contributions and, thus, does not successfully counteract the ratchet effect.

We identify two patterns explaining our main results. First, collective minimum contributions tend to be lower in case the collective minimum contribution mechanism is non-binding. Second, excess contributions, i.e., contributions above the suggested or required minimum, also tend to be lower if the mechanism is non-binding. Our data at the individual level reveals conditional cooperative dynamics to drive both patterns. We observe that both the minimum cooperation levels as well as participants' excess contributions decrease if other group members contribute less to the public good than the collectively determined minimum contribution level. Our main result with respect to policy making is therefore rather pessimistic: A non-binding minimum contribution mechanism lacks sufficient incentives to address the risk of being free-ridden and, therefore, fails to counteract the ratchet effect.

2 Experimental design, theoretical considerations, and procedures

2.1 General framework

Because our work complements Gallier and Sturm's (2021) experimental design, we first briefly describe the general framework of their public goods game. In the game, n identical players, $i = 1, \dots, n$, interact for T periods, $t = 1, \dots, T$. In each period t, player i receives a monetary endowment of w and decides which amount of her endowment to contribute to the public good, $g_{i,t}$, while the rest, $w - g_{i,t}$, goes to her private account. Her payoff in period t is given by $\pi_{i,t} = \alpha(w - g_{i,t}) - \beta(w - g_{i,t})^2 + \gamma G_t - \tau$ where $G_t = \sum_{j=1}^{n} g_{j,t}$ is the group's contribution to the public good in period t, and $\alpha > \gamma > 0$, $\beta > 0$, $\tau > 0$ are constants.[4] The term $\alpha(w - g_{i,t}) - \beta(w - g_{i,t})^2$ captures the benefit from her contribution to the private account and γG_t is the benefit from contributing to the public good. At the end of period T, player i receives the cumulated benefits from her contributions to the private account and the public good. Formally, her payoff at the end of period T equals:

$$\Pi_i = \sum_{t=1}^{T} \pi_{i,t} = \alpha \sum_{t=1}^{T} (w - g_{i,t}) - \beta \sum_{t=1}^{T} (w - g_{i,t})^2 + \gamma \sum_{t=1}^{T} G_t - \sum_{t=1}^{T} \tau$$

Thus, payoffs are linear in the contributions to the public good and concave in the contributions to the private account to capture decreasing marginal benefits from private consumption. This implies convex private opportunity costs of contributing to the public good. Depending on the choice of the parameters, this framework allows both the Nash equilibrium and the social optimum to lie in the interior of players' strategy space.

2.2 Treatments

In this paper, we extend the general framework by adding a collective minimum contribution mechanism to the public goods game. In our control condition (*BASE*), players play only one stage: the contribution stage. They anonymously and simultaneously decide in each period t about their

[4] A tax, τ, is used to calibrate payoffs. By subtracting τ it is possible to increase the relative distance between payoffs in the Nash equilibrium and the social optimum. Since τ is lump sum, it does not affect the incentives to contribute.

individual contribution to the public good, i.e., $0 \leq g_{i,t} \leq w$. In our ratcheting condition (*RAT*), players decide exactly as in *BASE*, but each contribution has to be at least as high as their contribution in the previous period, i.e., $g_{i,t-1} \leq g_{i,t} \leq w$. In the first period, the lower bound is equal to zero.

Implementing a collective minimum contribution mechanism requires an additional stage: the collective choice stage. Players first play the collective choice stage and then the contribution stage. In the collective choice stage, each player proposes an individual minimum contribution level to the public good, i.e., $\tilde{g}_i \in \{0, w\}$. The lowest common denominator of all proposals is selected and determines the collective minimum contribution, i.e., $g^{min} = \min\{\tilde{\boldsymbol{g}}\}$ where $\tilde{\boldsymbol{g}}$ is the set $\{\tilde{g}_1, \dots, \tilde{g}_n\}$ of all proposals. This is the minimum amount that each player has to contribute to the public good in the first period of the contribution stage. Then, from the second period of the contribution stage onwards, the ratchet-up mechanism applies such that players' public good contributions have to be at least as high as in the period before, i.e., $g_{i,t-1} \leq g_{i,t} \leq w$.

We study two types of collective minimum contribution mechanisms: a binding and a non-binding version. In *BminRAT*, the collective minimum contribution is binding. Players propose an individual minimum contribution level in the collective choice stage knowing that they have to contribute at least the lowest common denominator of all proposals in the first period of the contribution stage. That is, they are bound to contribute $g_{i,1} \geq g^{min}$ at the beginning of the contribution stage. From the second period onwards, the ratcheting condition applies such that they have to contribute at least as much as in the period before, i.e., $g_{i,t-1} \leq g_{i,t} \leq w$. In *NBminRAT*, the collective minimum contribution is also common knowledge, but – in contrast to *BminRAT* – it is non-binding. Players' decisions are identical to those in *BminRAT*, but they know that their contributions are finally not bound to the lowest common denominator. They can freely decide about their public good contribution levels in the first period of the contribution stage, i.e., $0 \leq g_{i,1} \leq w$ and therefore either stick to the minimum contribution levels or deviate from them. From the second period onwards, again, the ratcheting condition applies.[5] Table 1 summarizes our treatments.

[5] The exact wording in *NBminRAT* is as follows: "*In period 1, your individual contribution, q, should be at least as high as the collective minimum contribution. You can then decide to what extent you follow the suggestion*.". All instructions are available in Appendix D.

Table 1: Treatments

Treatment	Ratchet-up mechanism	Collective minimum contribution mechanism	Observations
BASE	No	No	39
RAT	Yes	No	37
NBminRAT	Yes	Non-binding	18
BminRAT	Yes	Binding	22
Total			116

Note: We have observations from 464 participants and consider contributions to the public good at the group level (n = 4) as independent observations. In total, this leads to 116 independent observations distributed across our four treatments. We augmented our data by using observations from Gallier and Sturm (2021) for those treatments which are completely identical in both experiments, i.e., 30 and 27 groups for *BASE* and *RAT*, respectively (see Section 2.4 "Procedure" for details).

2.3 Theoretical considerations

Purely rational and self-interested players in *BASE* maximize their cumulative payoff by choosing the unique Nash equilibrium in dominant strategies. Thus, player i in period t will choose the individually rational public good contribution level of $g_{i,t}^{*} = g^{*} \ = w + \frac{\gamma - \alpha}{2\beta}$. The socially optimal public good contribution level per player and period, in contrast, is given by $\mathring{g}_{i,t} = g^{\circ} \ = w + \frac{n\gamma - \alpha}{2\beta}$ (see Appendix A for the mathematical details).[6] This leads to a social dilemma where players' individually rational public good contribution level is below what would be socially optimal, if we have more than one player per group, i.e., $n > 1$.

Our ratcheting condition (*RAT*) prescribes that players have to contribute at least as much than what they have contributed before. This does not affect players' incentive structure: choosing g^{*} in every period remains the unique Nash equilibrium, such that $g_{i,t}^{RAT^{*}} = g^{*}$.

How do we expect collective minimum contributions to affect players' contributions to the public good? By design, if the collective minimum contribution is binding, players have a weakly dominant strategy to propose and contribute the socially optimal contribution level. The intuition is straightforward. In the first period of the contribution stage, players do not have an incentive to contribute more to the public good than the collective minimum, if it exceeds the individually rational contribution level of g^{*}. Individual public goods contributions are, therefore, given by $g_i = \max\{g^{min}, g^{*}\}$. By proposing a collective minimum contribution level in the collective choice stage, players have to take into account the potential impact of their proposal on their group members' contributions to the public good. If all other group members propose a collective

[6] Furthermore, we specify $n\gamma < \alpha < 2\beta w + \gamma$, such that our public goods game has interior solutions for both the Nash equilibrium as well as the social optimum.

minimum contribution equal or above the social optimum, i.e., $\min\{\tilde{\boldsymbol{g}}_{-i}\} \geq g^{\circ}$ where $\tilde{\boldsymbol{g}}_{-i}$ is the set $\{\tilde{g}_1, \dots, \tilde{g}_{i-1}, \tilde{g}_{i+1}, \dots, \tilde{g}_n\}$, player i maximizes her payoff by proposing the socially optimal contribution level: $\tilde{g}_i = g^{\circ}$. If, in contrast, at least one other group member proposes a collective minimum contribution level below the social optimum, i.e., $\min\{\tilde{\boldsymbol{g}}_{-i}\} < g^{\circ}$, player i should not propose a minimum below $\min\{\tilde{\boldsymbol{g}}_{-i}\}$, because this would lower the binding collective minimum contribution level for all group members and, thereby, reduce also her own payoff. By implication, it follows that also in this case player i can propose the socially optimal contribution level without taking the risk of making herself worse off. Thus, binding collective minimum contributions fully internalize the positive externality of contributing to the public good and, consequently, lead to a collective minimum contribution at the socially efficient level. Since players do not have an incentive to contribute more than required in the contribution stage, we expect all players to contribute the socially efficient public good contribution level in all periods of the contribution stage, such that $g_{i,t}^{BminRAT^*} = g^{\circ}$. These considerations lead to our first testable hypothesis:

HYPOTHESIS 1. Players in *BminRAT* will contribute more to the public good than those in *RAT*, i.e., $g_{i,t}^{BminRAT^*} > g_{i,t}^{RAT^*}$.

In *NBminRAT*, in contrast, the collective minimum contributions remain numerical cheap talk. The result of the collective choice stage is not binding and players are not bound to contribute at least the collective minimum contribution at the beginning of the contribution stage. Consequently, anticipating non-compliance with the minimum contribution level, we expect players to contribute the individually rational contribution level. This additional consideration suggests a second testable hypothesis:

HYPOTHESIS 2. Players in *NBminRAT* will contribute as much to the public good as those in *RAT*, i.e., $g_{i,t}^{NBminRAT^*} = g_{i,t}^{RAT^*}$.

2.4 Procedure

In our experiment, we chose parameters to meet the following conditions: (i) both the Nash equilibrium as well as the social optimum are interior solutions within subjects' strategy space, (ii) the difference between the Nash equilibrium and the social optimum is sufficiently large, and (iii) choosing the Nash equilibrium results in substantial efficiency losses. More precisely, group size $n = 4$, periods $T = 5$, endowment per period $w = 100$ LabDollar (LD), $\alpha = 4.4$, $\beta = 0.02$, $\gamma =$

1, and $\tau = 100$ LD. This leads to contributions of 15 LD per subject and period in the unique Nash equilibrium, i.e., 75 LD over all five periods. In the social optimum, in contrast, each subject contributes 90 LD per period, leading to 450 LD over all five periods. Individual payoffs in the social optimum are equal to 1,510 LD and are about 60% higher than those in the Nash equilibrium (947.5 LD).

We conducted the experiment online between October 2021 and February 2022, because physical interactions had to be suspended due to restrictions imposed to limit the spread of Covid-19. To address the problems raised by physical distance, we conducted online visually monitored sessions in line with the protocol suggested by Buso et al. (2021). We recruited students from the MaXLab laboratory of the Otto-von-Guericke-University of Magdeburg, Germany via hroot (Bock et al. 2012). The experiment was programmed in oTree (Chen et al. 2016) and we paid participants by bank transfer. Finally, we relied on a widely used web conferencing platform to moderate and monitor the sessions.

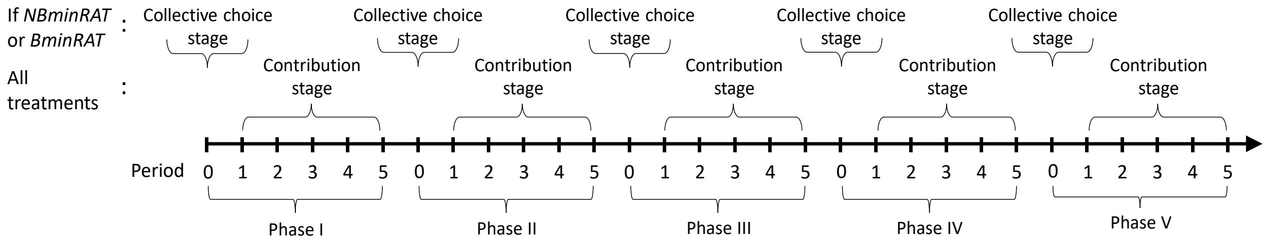
Already in the invitation, we informed participants that they will be connected via a web conferencing platform during the whole experiment. Participants who followed the invitation and registered for a session received a link from us via email to join the conferencing session. We used a web conferencing platform that guarantees that the experimenter can talk publicly to all participants. While participants can communicate privately with the experimenter, they cannot see nor communicate with each other. At the beginning of each session, we explained the general procedure to participants and sent them individual and anonymous links to start the experiment by email.

After log-in, participants were randomly assigned to groups of four players (partner matching). Participants received written instructions on their screens. Instructions included numerical examples and control questions. Furthermore, participants could use a payoff simulator and a payoff table to verify the numerical examples, answer control questions, and simulate different contribution decisions.[7] All these materials remained available throughout the sessions, by clicking a dedicated button. In case of questions, participants could use a chat function implemented both in the web conferencing platform and oTree.

---

[7] We provide all instructions in Appendix D. The payoff simulator calculated the individual payoff given the average contribution of other group members and the own contribution. The payoff table was a matrix which indicated the individual payoff in a period given average contributions by the other group members in columns and own contributions in rows (each in 5 LD steps from 0 LD to 100 LD).

Figure 1: Schematic overview



Note: In each phase (Phase I to V), participants play the contribution stage consisting of five periods of the public goods game (Period 1 to 5) each. In *BminRAT* and *NBminRAT*, participants also play the collective choice stage (Period 0). In addition, participants play a trial phase at the beginning of the game before the first phase starts. The trial phase includes the collective choice stage (only in *BminRAT* and *NBminRAT*) and the contribution stage with two non-payoff relevant periods.

During the game, information on group members' individual contributions to the public good, payoffs, and corresponding average values within the group was displayed on the screen after each period. In the treatments *BminRAT* and *NBminRAT*, in addition, the individual proposals for the group's minimum contribution were displayed. At the end of a session, participants completed a questionnaire. Finally, they were shown a receipt with the payment details and could leave the session.

Each session consisted of five consecutive but independent phases (Phase I to V). Figure 1 illustrates our stetting. In *BASE* and *RAT*, participants played only the contribution stage consisting of five periods of the public goods game (Period 1 to 5) in each phase. In *BminRAT* and *NBminRAT*, we inserted the collective choice stage (Period 0) immediately before the first period of the contribution stage in each phase. Before Phase I started, participants played a trial phase consisting of two non-payoff relevant practice periods. In *BminRAT* and *NBminRAT*, the trial phase additionally included a collective choice stage.

236 participants took part in our experiment. In addition to the already mentioned restrictions imposed to limit the spread of Covid-19, data collection was particularly challenging due to the limited number of potential participants within the subject pool at this time. To address this challenge, we augmented our dataset by merging existing observations from Gallier and Sturm (2021) for those treatments which are completely identical in both experiments, i.e., *BASE* and *RAT*. Those treatments follow exactly the same rules and instructions in both experiments, the only

difference is that they have been conducted in traditional physical laboratory sessions in Gallier and Sturm (2021).[8] By adding 30 groups of four participants each for *BASE* and 27 groups for *RAT*, we reach a total of 464 participants, i.e., 116 independent observations (see Table 1). Thus, our sample size allows us to detect treatment effects of at least half the size of those reported in the related literature at conventional levels of statistical inference, i.e., significance level of 5 percent and power of 80 percent.[9]

At the end of each session, cumulated earnings of one randomly chosen phase (out of the five phases) were selected to determine participants' earnings. Sessions lasted around 75 minutes and earnings ranged from 3.10 euros to 19.50 euros, with an average of 12 euros.

3. Results

3.1 Treatment effects

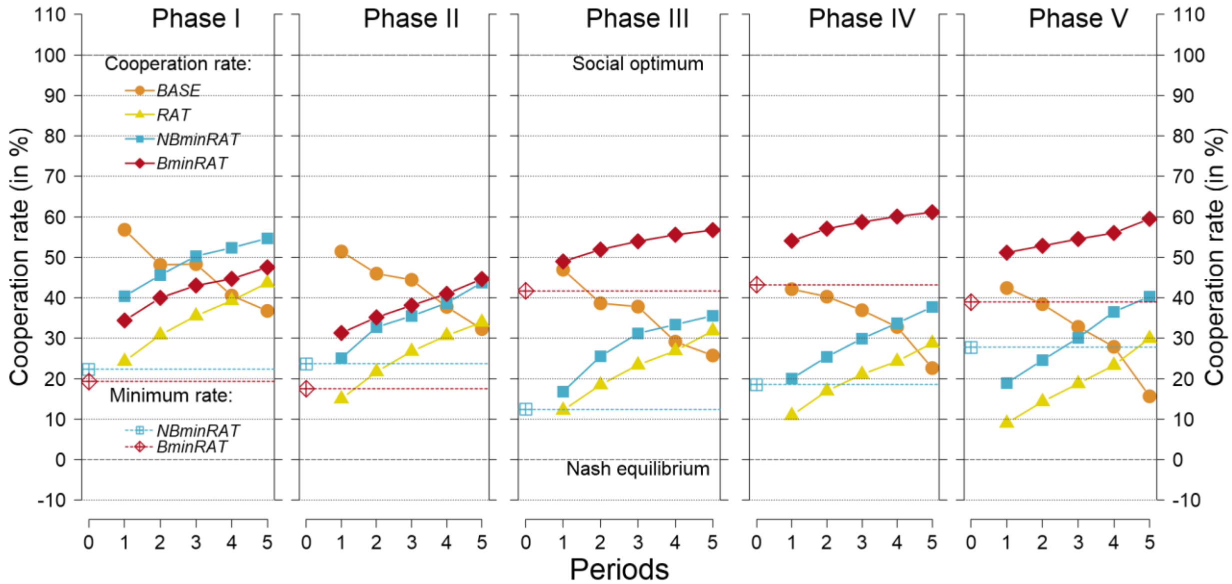
In this section, we present the average treatment effects. Figure 2 shows groups' average cooperation rates by treatment, phase, and period. In addition, it illustrates the collective minimum cooperation rates in *BminRAT* and *NBminRAT*. To ease interpretation, we pool observations per treatment and period over the five phases of the experiment. Figure 3 summarizes the main effects of *RAT*, *BminRAT*, and *NBminRAT* compared to *BASE*, both overall (*left*) as well as per period (*right*). We derive all estimates from a series of linear regression models and the corresponding ex-post Wald tests (see Table C.2 and C.3 in Appendix C).

Let us first compare the treatments *RAT* and *BASE*. In Period 1, cooperation rates in *RAT* are 33.7 percentage points lower compared to *BASE* (p-value < 0.0001, Table C.2 – Column 3). Even though cooperation rates in *RAT* increase over periods and finally exceed those in *BASE* by 7.0 percentage points in Period 5 (p-value = 0.0001, Table C.2 – Column 3), overall, these opposing trends are not strong enough to compensate for the loss in efficiency at the beginning of the game. In sum, there

[8] We find that participants behave very similarly in both settings. More precisely, we do not find significant differences in cooperation rates between our online visually monitored sessions and the physical laboratory setting in Gallier and Sturm (2021) (see Table C.1 in Appendix C). This is in line with Buso et al. (2021) who report that participants behave very similarly in a series of standard games (ultimatum, dictator, and public goods game) conducted either in a traditional physical laboratory or in online visually monitored sessions.

[9] See Appendix B for details.

Figure 2: Average cooperation rates: per phase, period, and treatment



Note: Average cooperation rates by treatments over phases and periods. Cooperation rates are given by $\left(\frac{g_{i,t}-g_{i,t}^{*}}{\mathring{g}_{i,t}-g_{i,t}^{*}}\right) \times 100\%$ to ease interpretation and assure that contributions at the Nash equilibrium and the social optimum correspond to 0 and 100 percent, respectively. For *BminRAT* and *NBminRAT*, we also indicate averages of collective minimum cooperation rates.

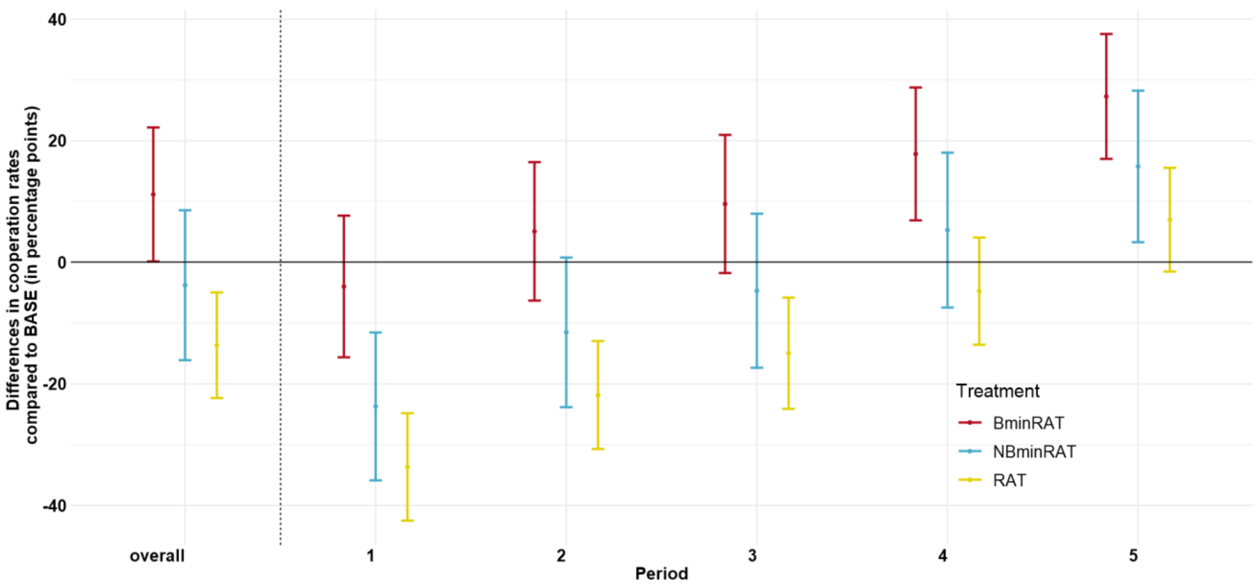
is a clear ratchet effect. Cooperation rates in *RAT* are significantly lower than those in *BASE* (p-value = 0.0105, Table C.2 – Column 1).[10]

Do collective minimum contributions counteract the ratchet effect? Figure 2 shows that both binding and non-binding collective minimum contributions tend to lift cooperation rates compared to *RAT*, but to very different orders of magnitude. Interestingly, while the effects of *BminRAT* and *NBminRAT* are about the same at the beginning of the experiment, i.e., in Phase I and II, substantial differences occur from Phase III onwards. Here, only binding collective minimum contributions counteract the ratchet effect. In total, Figure 2 suggests that while the effect of binding collective minimum contributions is substantial, it is rather modest for non-binding collective minimum contributions.

Binding collective minimum contributions significantly increase cooperation rates and thereby successfully counteract the ratchet effect. Overall, cooperation rates in *BminRAT* are about twice as high than those in *RAT* (49.3 vs. 24.5 percent, p-value = 0.0002, Table C.2 – Column 1).

[10] Appendix C shows that we find very similar patterns in the online visually monitored sessions and the laboratory setting in Gallier and Sturm (2021). There is a ratchet effect in both settings, even if it does not reach statistical significance in the online visually monitored sessions because small sample-size limit the statistical power of the comparison.

Figure 3: Treatment effects: overall and per period



Note: Difference in cooperation rates between *RAT*, *NBminRAT*, and *BminRAT* compared to *BASE*. We pool observations per treatment and period across the five phases of the experiment and report results overall (*left*) as well as per period (*right*). We calculate confidence intervals at the 90 percent level.

The effect is also remarkably stable over periods. The difference, for instance, is equal to 29.7 percentage points (p-value = 0.0001, Table C.2 – Column 3) and 20.3 percentage points (p-value = 0.0010, Table C.2 – Column 3) in Period 1 and 5, respectively.

That is, in line with our first hypothesis, we find that *BminRAT* does increase cooperation rates compared to *RAT*. To summarize:

RESULT 1. A binding collective minimum contribution mechanism counteracts the ratchet effect.

The effect of binding collective minimum contributions compared to *BASE* is less clear. In Period 1, cooperation rates in *BminRAT* tend to be lower than in *BASE*, however, the difference does not reach significance at conventional levels of statistical inference (p-value = 0.5751, Table C.2 – Column 3). Cooperation rates in *BminRAT* increase over periods and are significantly higher than those in *BASE* in Period 4 (p-value = 0.0074, Table C.2 – Column 3) and Period 5 (p-value < 0.0001, Table C.2 – Column 3). This leads to an overall difference in cooperation rates between *BminRAT* and *BASE* of 11.2 percentage points (p-value = 0.0953, Table C.2 – Column 1).

Although cooperation rates in *BminRAT* are significantly higher than those in *RAT* (p-value = 0.0002, Table C.2 – Column 1) and *BASE* (p-value = 0.0953, Table C.2 – Column 1), they clearly remain below the social optimum. More precisely, Figure 2 reveals that while cooperation rates in *BminRAT* show an increasing trend over phases, they never exceed 65 percent and, therefore, remain substantially below the social optimum of 100 percent.

We now turn to treatment *NBminRAT*. In contrast to the binding version, a non-binding collective minimum contribution mechanism does not significantly affect cooperation rates. Figure 3 shows that even though the cooperation rates in *NBminRAT* exceed those in *RAT* in all periods, overall, the differences do not reach significance at conventional levels of statistical inference (p-value = 0.1710, Table C.2 – Column 3). However, it is worth pointing out that the difference between *NBminRAT* and *RAT* is remarkably stable over periods. The difference is equal to 10.0 percentage points (p-value = 0.1559, Table C.2 – Column 3) and 8.8 percentage points (p-value = 0.2412, Table C.2 – Column 3) in Period 1 and 5, respectively. In sum and in line with our second hypothesis, we do not find that average cooperation rates in *NBminRAT* differ from those in *RAT*.

RESULT 2. A non-binding collective minimum contribution mechanism does not counteract the ratchet effect.

Figure 3 also reveals that cooperation rates in *NBminRAT* are significantly lower than those in *BASE* in Period 1 (p-value = 0.0014, Table C.2 – Column 3). Although cooperation rates in *NBminRAT* increase monotonically and exceed those in *BASE* in Period 5 (p-value = 0.0374, Table C.2 – Column 3), average cooperation rates do not differ between *NBminRAT* and *BASE* (p-value = 0.6141, Table C.2 – Column 3).

Next, we directly compare the effect of binding and non-binding collective minimum contributions. Overall, cooperation rates in *BminRAT* are 14.9 percentage points higher than in *NBminRAT* (p-value = 0.0730, Table C.2 – Column 3). This difference varies only marginally across periods. Thus:

RESULT 3. A binding collective minimum contribution mechanism leads to higher cooperation rates than a non-binding collective minimum contribution mechanism.

To explore the dynamics of groups' cooperative behavior in more detail, we next analyze cooperation rates per phase as well as across phases (see Figure 2). Already in Phase I, we observe a substantial ratchet effect. Cooperation rates in *RAT* are significantly lower than those in *BASE*

(34.7 vs. 46.1, p-value = 0.0409, Table C.4 – Column 1). Interestingly, both *BminRAT* (41.9 vs. 34.7, p-value = 0.3642, Table C.4 – Column 1) as well *NBminRAT* (48.6 vs. 34.7, p-value = 0.0951, Table C.4 – Column 1) tend to counteract the ratchet effect in the first phase. However, only the effect of non-binding collective minimum contributions reaches significance at conventional levels of statistical inference. Figure 2 also shows that cooperation rates decrease across phases in *BASE*, *RAT*, and *NBminRAT*. More precisely, cooperation rates decrease from Phase I to Phase V by 14.7 percentage points in *BASE* (p-value = 0.0002, Wilcoxon signed rank test), by 15.6 percentage points in *RAT* (p-value = 0.0001, Wilcoxon signed rank test), and by 18.3 percentage points in *NBminRAT* (p-value = 0.0665, Wilcoxon signed rank test). In *BminRAT*, in contrast, cooperation rates increase from 41.9 percent in Phase I to 54.8 percent in Phase V (p-value = 0.5235, Wilcoxon signed rank test). In Phase II, consequently, neither *BminRAT* (38.0 vs. 25.6, p-value = 0.1179, Table C.4 – Column 2) nor *NBminRAT* (35.1 vs. 25.6, p-value = 0.275, Table C.4 – Column 2) counteract the ratchet effect significantly. This changes in Phase III. Here, cooperation rates in *BminRAT* increase substantially and are significantly higher than those in *RAT* (53.4 vs. 22.5, p-value = 0.0014, Table C.4 – Column 3). Furthermore, they remain at a comparatively high level to the end of the experiment. Non-binding collective minimum contributions, in contrast, do not counteract the ratchet effect anymore (28.5 vs. 22.5, p-value = 0.4817, Table C.4 – Column 3). These trends help to explain that overall only *BminRAT* counteracts the ratchet effect and, furthermore, lead to an especially pronounced treatment effect in the last phase of the experiment. Having a closer look at Phase V, we observe that the ratchet effect is substantial and statistically significant (see Table C.2 – Column 4 and Table C.3 – Panel B). Average cooperation rates in *RAT* are 12.4 percentage points lower than those in *BASE* (p-value = 0.0312, Table C.2 – Column 4). Although *NBminRAT* also counteracts the ratchet effect at the beginning of the experiment, Phase V clearly shows that only binding collective minimum contributions have an effect at the end of the experiment. In *BminRAT*, groups achieve a cooperation rate of 54.8 percent, which is substantially and significantly higher than the cooperation rate of 19.1 percent in *RAT* (p-value < 0.0001, Table C.2 – Column 4). In addition, cooperation rates in *BminRAT* are statistically significantly higher than those in *NBminRAT* (p-value = 0.036, Table C.2 – Column 4).

Table 2: Decomposed cooperation rates in *BminRAT* and *NBminRAT*

	Cooperation rate	Minimum cooperation rate	Excess cooperation rate
Panel A. *BminRAT*			
	43.96***	32.12***	11.84***
	(5.736)	(6.633)	(2.192)
Panel B. *NBminRAT*			
	24.23***	20.95***	3.28
	(6.115)	(6.778)	(4.634)
Panel C. Difference between *BminRAT* and *NBminRAT*			
	19.73**	11.17	8.56
	(8.384)	(9.484)	(5.126)

Note: Average cooperation rates in first period per phase decomposed into the minimum and excess cooperation rates in *BminRAT* (Panel A), *NBminRAT* (Panel B), as well as for the difference between *BminRAT* and *NBminRAT* (Panel C). * p<0.10, ** p<0.05, and *** p<0.01.

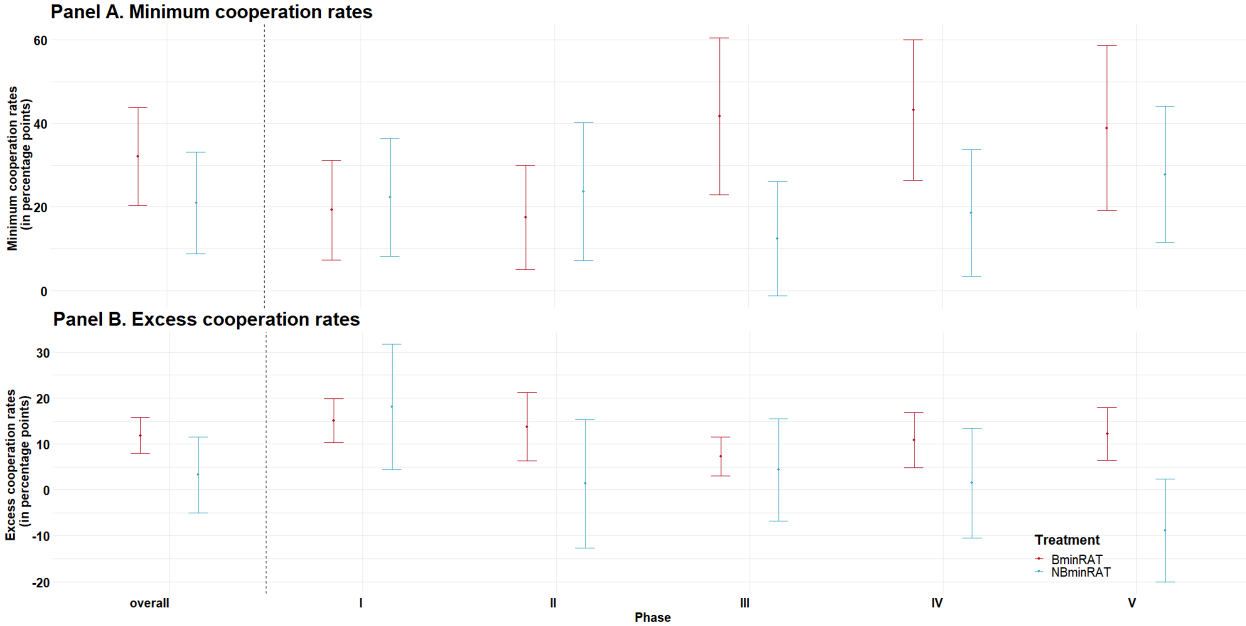
Finally, cooperation rates in *NBminRAT* are not statistically distinguishable from those in *BASE* (p-value = 0.8818, Table C.2 – Column 4) and *RAT* (p-value = 0.1964, Table C.2 – Column 4). Thus, Phase V reveals that all treatment effects are particularly pronounced at the end of the experiment.

3.2 Decomposing treatment effects

Why do only binding collective minimum contributions counteract the ratchet effect? Our answer to this question relies on the decomposition of groups' average cooperation rates. The idea is simple. We decompose the average cooperation rates in the first period per phase into two components: First, the collective minimum that players have to (in *BminRAT*) or should (in *NBminRAT*) contribute to the public good. Second, the excess cooperation rates that captures the difference between the actual cooperation rates and the required (in *BminRAT*) or suggested (in *NBminRAT*) minimum cooperation rates.

Table 2 summarizes the results of our decomposition in *BminRAT* (Panel A) and *NBminRAT* (Panel B) as well as for the difference between *BminRAT* and *NBminRAT* (Panel C). Cooperation rates in the first period of the first phase in *BminRAT* are 19.7 percentage points higher than those in *NBminRAT* (p-value = 0.0239, Table 2 – Panel C). Our decomposition reveals that this effect is

Figure 4. Minimum and excess cooperation rates: overall and per phase



Note: Minimum (Panel A) and excess cooperation rates (Panel B) in *BminRAT* and *NBminRAT*. We report results overall (*left*) as well as per phase (*right*). We calculate confidence intervals at the 90 percent level.

driven both by differences in the minimum cooperation rates and the excess cooperation rates. Minimum cooperation rates (+11.2 percentage points, p-value = 0.2461, Table 2 – Panel C) as well as excess cooperation rates (+8.6 percentage points, p-value = 0.1031, Table 2 – Panel C) in *BminRAT* exceed those in *NBminRAT*.

Having decomposed the average cooperation rates into the minimum and excess cooperation rates, our next step is to examine how these evolve over the course of the experiment. Figure 4 compares the minimum cooperation rates (Panel A) and excess cooperation rates (Panel B) in *BminRAT* and *NBminRAT*, both overall (*left*) as well as per phase (*right*). Interestingly, we do not find substantial differences between *BminRAT* and *NBminRAT* in Phase I of the experiment, neither in the minimum (19.3 vs. 22.3, p-value = 0.7732, Table C.5 – Panel A) nor the excess cooperation rates (15.1 vs. 18.1, p-value = 0.7158, Table C.5 – Panel A). During the experiment, however, cooperation rates start to differ. More precisely, in *BminRAT*, minimum cooperation rates increase to about 40 percent in Phase III and remain at this high level until Phase V (see Figure 4 – Panel A). In contrast, they remain at comparatively low levels in *NBminRAT*. As a result, in Phase III and IV, the differences between the minimum contribution rates in *BminRAT* and *NBminRAT* reach significance at conventional levels of statistical inference (Phase III: p-value = 0.0318, Table C.5 – Panel C; Phase IV: p-value = 0.0613, Table C.5 – Panel D). This leads to our fourth result:

RESULT 4. Minimum cooperation rates in *BminRAT* are higher than those in *NBminRAT* in Phases III and IV.

In our view, these patterns suggest that a binding minimum contribution mechanism could serve as a coordination mechanism, but that participants need time to learn and coordinate before the mechanism can take effect. Finally, we observe different end-round effects. While minimum cooperation rates in *NBminRAT* increase between Phase IV and V, they tend to slightly decrease in *BminRAT*. The difference in minimum cooperation rates between *BminRAT* and *NBminRAT*, thus, does not reach statistical significance in Phase V of the experiment (38.9 vs. 27.8, p-value = 0.4458, Table C.5 – Panel E).

We now turn to analyze the excess cooperation rates per treatment over the course of the experiment (see Figure 4 – Panel B). Overall, excess cooperation rates in *BminRAT* are positive and statistically significantly different from zero (p-value < 0.001, Table 2 – Panel A, Column 3). In *NBminRAT*, in contrast, the excess cooperation rates are statistically not distinguishable different from zero. Excess cooperation rates between the two treatments also start to differ over the course of the experiment. While excess cooperation rates in *BminRAT* remain rather stable across phases, they decrease from phase to phase in *NBminRAT* and become even negative in Phase V. That is, in Phase V, subjects in *NBminRAT* contribute less than the collectively chosen minimum contribution level on average. In sum, the difference between excess cooperation rates in *BminRAT* and *NBminRAT* is especially pronounced in Phase V of the experiment (12.2 vs. -8.9, p-value = 0.005, Table C.5 – Panel E). This is our fifth result:

RESULT 5. Excess cooperation rates in *BminRAT* are higher than those in *NBminRAT* in Phase V.

We interpret this as an end-round effect that could suggest that even those participants in *NBminRAT* who have complied with the collective minimum cooperation rate so far, start to deviate in the last phase of the experiment and contribute less than the collectively chosen minimum.

3.3 Discussing differences in treatment effects

In this section, we identify two patterns that could help to explain why both the collective minimum cooperation rates as well as participants' excess cooperation rates are lower in *NBminRAT* than in

BminRAT. To do so, we analyze participants' decisions in *NBminRAT* with a special focus on how compliance – respectively non-compliance – with the collectively chosen minimum cooperation rate within a group affect the dynamics throughout the experiment. The analysis in Table 3 shows how non-compliance with the committed minimum cooperation rate in a given phase affects both collective minimum cooperation rates (see Table 3 – Panel A) as well as participants' excess cooperation rates (see Table 3 – Panel B) in the subsequent phase of the experiment. In Panel A, we use groups' minimum cooperation rates in Phase II to V as dependent variable and regress it on the number of participants per group who do not comply with the collective minimum cooperation rate in the first period of the previous phase, i.e., Phase I to IV, respectively. We observe that non-compliance with the collective minimum cooperation rate by a player per group reduces the collectively chosen minimum cooperation rate in the subsequent phase on average by eight percentage points (p-value = 0.0027, Table 3 – Panel A). Furthermore, we find that this effect is particularly pronounced in Phase III (p-value = 0.0113, Table 3 – Panel A) and Phase IV (p-value = 0.0035, Table 3 – Panel A).

Having identified that non-compliance with collective minimum cooperation rate in one phase of the experiment decreases the collectively chosen minimum cooperation rate in the next phase, we now shift our analysis to participants' individual decisions to explore the mechanisms driving this effect (see Table C.6 and Table C.7 in Appendix C). First, we repeat the analysis in Table 3 – Panel A, but use participants' individual proposals for the collective minimum cooperation rate as dependent variable. We find a very similar pattern. Participants reduce their proposals in response to other group members not complying with the collectively chosen minimum cooperation rate in the first period of the previous phase (p-value = 0.0046, Table C.6 – Column 1). Second, we study whether this effect is driven by *Initial Non-Compliers*, i.e., those participants who do not comply with the collective minimum cooperation rate in Period 1 of Phase I of the experiment, or *Initial Compliers*, i.e., those participants who comply. Overall, only *Initial Compliers* reduce their proposed minimum cooperation rates if other group members contribute less than committed (-3.701, p-value < 0.01, Table C.7 – Panel A). *Initial Non-Compliers*, in contrast, show a negative effect only in the last phase of the experiment, reducing their proposals in Phase V as a response to non-compliance by other group members in Phase IV (p-value = 0.0404, Table C.7 – Panel B).

Table 3 – Panel B analyzes how the excess cooperation rates in the first period of a given phase are affected by non-compliance with the collective minimum cooperation rate in the previous phase.

Table 3: Effects of non-compliance on minimum and excess cooperation rates

	Overall	Phase II	Phase III	Phase IV	Phase V
Panel A. Minimum cooperation rates					
	-8.024***	-2.441	-11.199**	-9.378**	-8.355
	(2.647)	(6.668)	(4.390)	(4.421)	(5.811)
Panel B. Excess cooperation rates					
	-9.842***	-13.664*	-7.090*	-6.209	-14.162***
	(2.489)	(7.246)	(4.092)	(3.849)	(4.759)

Note: We only use observations from *NBminRAT*. In Panel A, we use groups' collectively chosen minimum cooperation rates in Phase II to V as dependent variable. The explanatory variable is the number of players within a group who provide a cooperation rate below the collective minimum cooperation rate in Period 1 of the previous phase, i.e., a count variable ranging from 0 (only Compliers) to 4 (no Compliers). In Panel B, we use participants' excess cooperation rates in Period 1 of Phase II to V as dependent variable. As independent variable we use the number of other group members who provide a cooperation rate below the collective minimum cooperation rate in Period 1 of the previous phase, i.e., a count variable ranging from 0 (only Compliers) to 3 (no Compliers). We report results on average for Phase II to V as well as separately per phase. Robust standard errors are clustered on group level and subject level in Panel A and B, respectively. * p<0.10, ** p<0.05, and *** p<0.01.

More precisely, we regress the number of other group members who do not comply with the collectively chosen cooperation rate in the previous phase on participants' excess cooperation rates in the current period.

The results indicate that non-compliance by another group member in the previous phase reduces participants' excess cooperation rates by ten percentage points in the subsequent phase (p-value = 0.0002, Table 3 – Panel B). This effect is particularly pronounced in Phase II (p-value = 0.0604, Table 3 – Panel B) and Phase V (p-value = 0.0032, Table 3 – Panel B). Finally, we investigate whether this effect is driven by *Initial Compliers* or *Initial Non-Compliers* (see Table C.7 in Appendix C). We find that *Initial Compliers* largely drive the negative effect on the excess cooperation rate. While *Initial Compliers* respond to non-compliant behavior with reducing their excess cooperation rates by 11 percentage points (p-value = 0.0003, Table C.7 – Panel A), *Initial Non-Compliers* in contrast do not significantly adjust their excess cooperation rate accordingly (p-value = 0.7110, Table C.7 – Panel B).

In sum, participants' reactions to other group members who do not complying with the collectively chosen minimum cooperation rate help us to explain the differences between *BminRAT* and *NBminRAT*. By design, only in *NBminRAT* participants have the opportunity to deviate from the collective minimum. We report that such a form of non-compliance in a given phase reduces both the collective minimum cooperation rate as well as participants' excess cooperation rates in the subsequent phase (see Section 3.2), and thus ultimately the cooperation rate (see Section 3.1).

Interestingly, these effects are predominantly driven by *Initial Compliers*. One plausible interpretation is that especially *Initial Compliers* adapt their behavior and react conditionally cooperative (e.g., Fischbacher et al. 2001) to other group members who do not comply with the collectively chosen minimum cooperation rates. Thus, although cooperation rates are remarkably similar between *BminRAT* and *NBminRAT* at the beginning of the experiment (see Figure 2), the described conditionally cooperative dynamics can explain why cooperation rates in *NBminRAT* decrease from phase to phase and are lower on average of all phases than in *BminRAT*.

4. Conclusion

Our paper provides an initial experiment to testbed a theoretically promising amendment to the ratchet-up mechanism of the Paris Agreement. The amendment stipulates that all agents propose a collective minimum contribution to the public good knowing that they are supposed to contribute at least the lowest common denominator of all proposals.

The main findings can be summarized briefly: First, the ratchet-up mechanism leads to comparatively low cooperation rates. This supports the ratchet effect reported by Gallier and Sturm (2021) and provides further evidence that the mechanism in its current form increases the risk of being free-ridden and, thus, reduces cooperation. Second, in line with our theoretical considerations, a binding collective minimum contribution mechanism has a substantial impact on participants' cooperation behavior and successfully counteracts the ratchet effect. Overall and all else equal, a binding collective minimum contribution mechanism increases cooperation rates by about 25 percentage points. Third, a non-binding collective minimum contribution mechanism, in contrast, does not promote cooperation and, thus, fails to successfully address the ratchet effect.

In our view, a key observation is that cooperation rates start at the same level in both collective minimum contribution mechanisms at the beginning of the experiment, but then show different trends: While cooperation rates increase over time with binding collective minimum cooperation rates, they decrease if the collective minimum cooperation rates are non-binding. In this line, both collective minimum cooperation rates as well as participants' excess cooperation rates are lower in case the collective minimum mechanism is non-binding. Consistent with conditional cooperative dynamics, we find that participants' compliance behavior could help to explain this observation. We observe that non-compliance with the non-binding collective minimum is negatively reciprocated. Non-compliant group members in a given phase of the experiment cause decreasing collective minimum cooperation rates as well as excess cooperation rates in the subsequent phase.

Interestingly, especially participants who behave cooperatively at the beginning of the experiment respond strongly to deviations from the collective minimum cooperation rates by other group members. This highlights that especially early-stage non-compliance inhibits successful cooperation by eroding the mechanism's potential as a cooperation and coordination device. A non-binding minimum contribution mechanism, therefore, lacks sufficient incentives to address the risk of being free-ridden by non-complying participants and therefore fails to counteract the ratchet effect. This also suggests that the ratchet effect is not predominantly driven by a potential lack of coordination devices.

What lessons can we draw for international climate policy, in particular, the Paris Agreement? In sum, the implications of our results are rather pessimistic. First, while the binding minimum contribution mechanism does promote cooperation in the laboratory, it is difficult to imagine that such a strict mechanism could be implemented and enforced in multilateral interactions of sovereign parties. Second, even though a weaker non-binding minimum coordination mechanism preserves certain aspects of parties' sovereignty and could serve as a commitment and coordination device to promote cooperation at the international level, it does not increase efficiency and fails to counteract the ratchet effect in our experiment. In particular, it lacks sufficient incentives to address the risk of being free-ridden. Thus, even when supplemented by a non-binding minimum contribution mechanism, the ratchet-up mechanism has a decisive weakness: It prevents sufficiently high mitigation efforts in the near future, thereby shifting the burden to later periods. This stands in conflict with the frequent call for rapid and deep emissions reductions (e.g., IPCC 2022). Moreover, a non-binding minimum contribution mechanism appears to be too weak as a coordination device to curb unilateral deviation and the negative consequences associated. This implies that any attempt to counteract the ratchet effect has to address at least two challenges: First, it has to ensure sufficiently high and credible commitments at the beginning of the game. Second, it has to break the *vicious cycle* that those agents who do not comply with the commitments increase the risk that others will not comply in the future either.

After outlining the possible implications of our study for international climate policy, we discuss the generalizability of our results. We highly encourage any replication and extension of our initial attempt to design and testbed an amendment to the ratchet-up mechanism within the Paris Agreement for several reasons. First, as we should not base policy recommendations on a single study, we do not want to put too much emphasis on the precise magnitude of our treatment effects and are convinced that more evidence is needed to improve our understanding of the mechanisms driving the ratchet effect and potential solutions. Nevertheless, our results clearly indicate that the ratchet-up mechanism reduces cooperation and that a binding collective minimum mechanism could improve cooperation. A non-binding collective minimum mechanism, in contrast, does not promote cooperation. Second, as a non-binding minimum cooperation mechanism already fails to counteract the ratchet effect in our "*petri dish*" of a highly stylized laboratory experiment, our prior is that it is even more unlikely to promote cooperation in any field of application outside of the laboratory, in particular, in international climate policy. Negotiations outside of the laboratory are much richer in context than our experimental design that we deliberately tried to keep as simple as possible to provide a first and clean test of a theoretically promising amendment to the ratchet-up mechanism. As aspects like, for instance, leadership, sanctioning mechanisms, and different forms of communication may alter the relative performance of collective minimum mechanisms outside of the laboratory, we consider further experimental and empirical investigation of different institutions and possible adjustments to the proposed mechanism as fruitful areas for further research.

References

Barrett, S. 1994. Self-enforcing international environmental agreements. *Oxford Economic Papers* 46, 878-94.

Barrett, S. and Dannenberg, A. 2016. An experimental investigation into "pledge and review" in climate negotiations. *Climatic Change* 138, 339–51.

Barrett, S. and Dannenberg, A. 2022. The decision to link trade agreements to the supply of global public goods. *Journal of the Association of Environmental and Resource Economists* 9, 273-305.

Bochet, O. and Putterman, L. 2009. Not just babble: Opening the black box of communication in a voluntary contribution experiment. *European Economic Review* 53, 309-326.

Bock, O., Baetge, I., Nicklisch, A. 2015. hroot: Hamburg registration and organization online tool. *European Economic Review* 71, 117-120.

Buso, I.M., Cagno, D.D., Ferrari, L., Larocca, V., Lorè, L., Marazzi, F., Panaccione, L., and Spadoni, L. 2021. Lab-like findings from online experiments. *Journal of the Economic Science Association* 7, 184-193.

Cason, T.N. 1995. An experimental investigation of the seller incentives in the EPA's emission trading auction. *American Economic Review* 85, 905-922.

Cason, T.N. and Plott, C.R. 1996. EPA's new emissions trading mechanism: A laboratory evaluation. *Journal of Environmental Economics and Management* 30, 133-160.

Cason, T., Stranlund, J., and de Vries, F. forthcoming. Investment incentives in tradeable emission markets with price floors. *Journal of the Association of Environmental and Resource Economists*.

Chen, D.L., Schonger, M., and Wickens, C. 2016. oTree—An open-source platform for laboratory, online, and field experiments. *Journal of Behavioral and Experimental Finance* 9, 88-97.

Dannenberg, A., Lange, A., and Sturm, B. 2014. Participation and commitment in voluntary coalitions to provide public goods. *Economica* 81, 257-275.

Fischbacher, U., Gächter, S. and Fehr, E. 2001. Are people conditionally cooperative? Evidence from a public goods experiment. *Economics Letters* 71, 397-404.

Gallier, C. and Sturm, B. 2021. The ratchet effect in social dilemmas. *Journal of Economic Behavior and Organization* 186, 251-268.

Gallier, C., Kesternich, M., and Sturm, B. 2017. Voting for burden sharing rules in public goods games. *Environmental and Resource Economics* 67, 535-557.

IPCC 2022. Climate Change 2022 Mitigation of Climate Change, https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SPM.pdf, S. 28 C.3

Kesternich, M., Lange, A., and Sturm, B. 2014. The impact of burden sharing rules on the voluntary provision of public goods. *Journal of Economic Behavior & Organization* 105, 107-123.

Koessler, A.-K. 2022. Pledges and how social influence shapes their effectiveness. *Journal of Behavioral and Experimental Economics* 98, 101848.

Noussair, C.N. and van Soest, D.P. 2014. Economic experiments and environmental policy: A review. *Annual Review of Resource Economics* 6, 319-337.

Orzen, H. 2008. Fundraising through competition: evidence from the lab. CeDEx Discussion Paper 2008-11, University of Nottingham.

Rogelj, J., den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., Schaeffer, R., Fu Sha, F., Riahi, K., Meinshausen, M. 2016. Paris Agreement climate proposals need a boost to keep warming well below 2 °C. *Nature* 534, 631-639.

Schmidt, K. and Ockenfels, A. 2021. Focusing climate negotiations on a uniform common commitment can promote cooperation. *Proceedings of the National Academy of Sciences of the United States of America* 118, 1-6.

Sturm, B. and Weimann, J. 2006. Experiments in environmental economics and some close relatives. *Journal of Economic Surveys* 20, 419-457.

UNEP 2021. Emissions Gap Report 2021: The Heat Is On, https://wedocs.unep.org/bitstream/handle/20.500.11822/36991/EGR21_ESEN.pdf

UNFCCC 2015. Paris Agreement. United Nations, https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf.

Appendices

This document contains the appendices for the paper "Collective minimum contributions to counteract the ratchet effect in the voluntary provision of public goods" by Marius Alt, Carlo Gallier, Martin Kesternich, and Bodo Sturm.

Appendix A derives and presents the individually rational and socially optimal contribution levels in *BASE* used as benchmarks in Section 2.3 of the main body of the text.

Appendix B explains the details of our power calculations used in Section 2.4 of the main body of the text.

Appendix C presents and discusses additional results for the analyses in the main body of the text.

Appendix D contains the instructions for the laboratory experiment.

Appendix A. Nash equilibrium and social optimum in *BASE*

In this section of the appendix, we derive the individually and socially optimal contribution levels in *BASE* under the assumption that subjects are rational and purely self-interested.

Appendix A.1 Nash equilibrium

The cumulative payoff function for subject i, $i = 1, \dots n$, over all T periods is given by

$$\Pi_i = \sum_{t=1}^{T} \pi_{i,t} = \alpha \sum_{t=1}^{T} (w - g_{i,t}) - \beta \sum_{t=1}^{T} (w - g_{i,t})^2 + \gamma \sum_{t=1}^{T} G_t - \sum_{t=1}^{T} \tau \quad \text{(Eq. A.1.1)}$$

where $G_t = \sum_{i=1}^{n} g_{i,t}$ is the group contribution to the public good in period t. The first order condition (FOC) for payoff maximization in the last period T is given by

$$\frac{\partial \Pi_i}{\partial g_{i,T}} = -\alpha + 2\beta (w - g_{i,T}) + \gamma = 0. \quad \text{(Eq. A.1.2)}$$

Eq. A.1.2 shows that individual payoff maximization requires that the marginal benefits from contributing to the private and public account are equal. If participants contribute one unit less to the private account, their benefit from the private account decreases by $\alpha - 2\beta(w - g_{i,T})$ which can be interpreted as the marginal private opportunity costs of contributing more to the public good. Thus, in equilibrium, marginal benefits are equal to marginal private opportunity costs of contributing to the public good, i.e., $\gamma = \alpha - 2\beta(w - g_{i,T})$. From this, we obtain the payoff-maximizing contribution level in T

$$g_{i,T}^{*} = w + \frac{\gamma - \alpha}{2\beta}. \quad \text{(Eq. A.1.3)}$$

Since the decision situation in all other $T - 1$ periods is exactly the same, the unique individual Nash equilibrium contribution level in dominant strategies in any period $t = 1, \dots, T$ is given by

$$g_{i,t}^{*} = g^{*} = w + \frac{\gamma - \alpha}{2\beta}. \quad \text{(Eq. A.1.4)}$$

Appendix A.2 Social optimum

In order to determine the individual public good contributions in the social optimum, we consider the cumulated group payoff function

$$\Pi = \sum_{i=1}^{n} \Pi_i = \alpha \sum_{t=1}^{T} (W - G_t) - \beta \frac{1}{n} \sum_{t=1}^{T} (W - G_t)^2 + \gamma n \sum_{t=1}^{T} G_t - n \sum_{t=1}^{T} \tau \quad \text{(Eq. A.2.1)}$$

where W is the group's endowment and $G_t = \sum_{i=1}^{n} g_{i,t}$ is the group's contribution to the public good in period t. In the last period T, we obtain the following FOC

$$\frac{\partial \Pi}{\partial G_T} = -\alpha + 2\beta \frac{1}{n} (W - G_T) + \gamma n = 0 \quad \text{(Eq. A.2.2)}$$

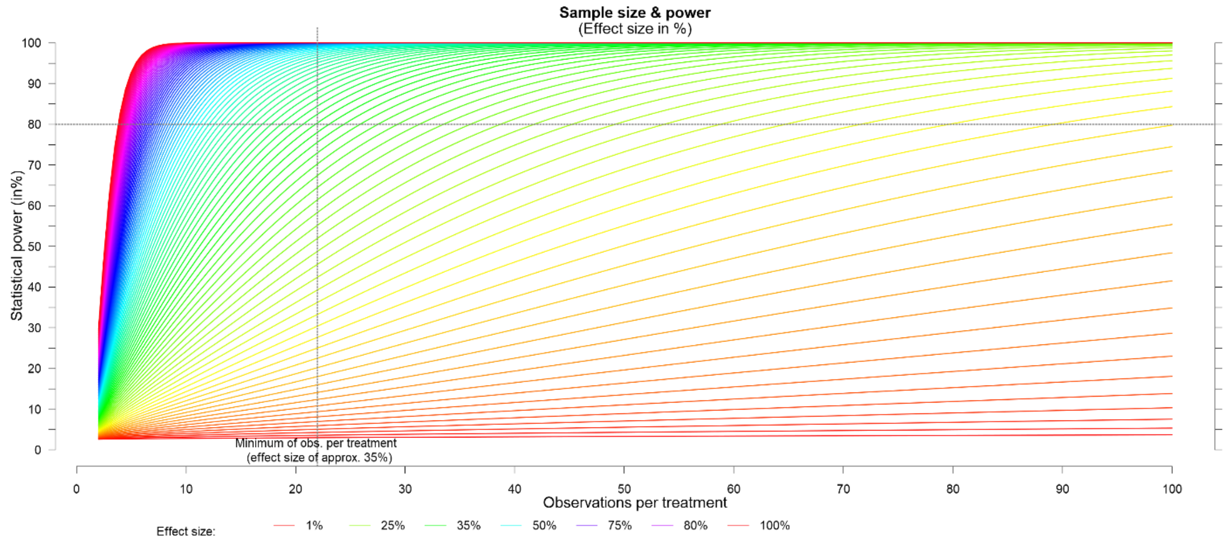
and an individual public good contribution level in the social optimum of

$$g^{\circ}_{i,T} = g^{\circ}_{i,t} = g^{\circ} = w + \frac{n\gamma - \alpha}{2\beta}. \qquad \text{(Eq. A.2.3)}$$

For this, we use $W = nw$ and $G^{\circ}_{T} = ng^{\circ}_{i,T}$, since subjects are identical.

Appendix B. Power calculation

Figure B.1: Power curves for different effect sizes of collective minimum contributions



Note: We simulate a variety of different treatment effects of *BminRAT* compared to *RAT* ranging from 1 percent to 100 percent of participants' public good contributions in *RAT*.

We base our power calculation on two closely related papers. First, we took the data from the weak ratcheting treatment (*weakR*) of Gallier and Sturm (2021) to assess participants' public good contributions in our ratcheting treatment (*RAT*). Second, we use the information reported in Dannenberg et al. (2014) to derive a prior for the effect of implementing binding collective minimum contributions in our *BminRAT* treatment. Building on this, we simulate a variety of potential treatment effects for our *BminRAT* treatment ranging from 1 percent to 100 percent of participants' public good contributions in *RAT*.

Next, we base our power calculations on two-sided t-tests of means per treatment with independent samples conducted with R[11] using the "pwr"[12] package. Figure B.1 illustrates the results. With a minimum of 22 independent observations in *BminRAT*, we can detect treatment effects of 35 percent of contribution levels in *RAT* and more at conventional levels of statistical significance (5 percent) and power (80 percent). Put differently, we are able to detect a treatment effect comparable to our prior derived from Dannenberg et al. (2014) at a very high level of statistical power with more than 99 percent.

[11] R Core Team, 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/

[12] Champely, S., 2018. pwr: Basic functions for power analysis. R package version 1.3-0. https://cran.r-project.org/web/packages/pwr/

Appendix C. Additional analyses

Table C.1: Mean cooperation rates in Gallier and Sturm (2021) and our experiment

Treatments	Period	Gallier and Sturm (2021)	Our experiment	p-value
Panel A. *base* vs. *BASE*				
	1	49.42	42.98	0.6127
	2	44.10	36.21	0.5365
	3	41.52	35.14	0.5965
	4	35.35	27.84	0.4454
	5	28.66	19.73	0.2815
	overall	39.81	32.38	0.4971
Panel B. *weakR* vs. *RAT*				
	1	11.25	22.46	0.2964
	2	17.99	27.10	0.3812
	3	22.99	30.78	0.4635
	4	27.08	33.73	0.5189
	5	32.37	36.99	0.6508
	overall	22.34	30.21	0.4476

Note: Panel A, difference between cooperation rates in treatment *base* of Gallier and Sturm (2021) (n = 30) and *BASE* of our experiment (n = 9). Panel B, difference between cooperation rates in treatment *weakR* of Gallier and Sturm (2021) (n = 28) and *RAT* of our experiment (n = 10). All p-values rely on two-sided Mann-Whitney U tests.

Table C.1 shows two important insights. First, we do not find evidence for systematic differences between the laboratory setting in Gallier and Sturm (2021) and our online visually monitored sessions. In those treatments which are perfectly comparable in both settings (*base* vs. *BASE* and *weakR* vs. *RAT*), participants' cooperation rates show no significant differences, neither overall nor per period. Second, our replication of the ratchet-up mechanism generates a pattern which is very similar to that observed in Gallier and Sturm (2021). Thus, we also find support for a ratchet effect if we restrict our data to the online visually monitored sessions. At the beginning, participants in *RAT* start with substantially lower cooperation rates than those in *BASE*. Cooperation rates in Period 1 in *RAT* are 20.52 percentage points lower than those in *BASE* (p-value = 0.157). However, because small sample-size limit statistical power, the difference does not reach significance at conventional levels of statistical inference. While cooperation rates increase over time in *RAT* and decrease in *BASE*, these trends are not strong enough to counteract the ratchet effect. Overall, cooperation rates in *RAT* are lower than those in *BASE* (p-value = 0.7171). Due to small sample-size, the difference does not reach statistical significance.

Table C.2: Treatment effects

	Dependent Variable: Cooperation rate (in percent)					
	All phases (Phase I – V)			Phase V		
	(1)	(2)	(3)	(4)	(5)	(6)
RAT	-13.631**	-13.631***	-33.652***	-12.364**	-12.364***	-33.393***
	(5.236)	(2.510)	(5.363)	(5.667)	(2.843)	(5.824)
BminRAT	11.174*	11.174***	-3.966	23.364**	23.364***	8.743
	(6.642)	(3.090)	(7.071)	(9.802)	(4.539)	(10.351)
NBminRAT	-3.759	-3.759	-23.700***	-1.361	-1.361	-23.486***
	(7.436)	(3.480)	(7.382)	(9.129)	(4.355)	(8.999)
Period 2		1.731	-5.650		1.557	-3.983
		(3.343)	(5.884)		(4.154)	(7.045)
Period 3		3.611	-7.882		2.264	-9.590
		(3.356)	(5.986)		(4.168)	(7.229)
Period 4		3.544	-14.315**		3.333	-14.513*
		(3.342)	(5.797)		(4.220)	(7.407)
Period 5		3.700	-21.328***		2.583	-26.744***
		(3.382)	(5.587)		(4.219)	(6.541)
RAT x Period 2			11.823			9.307
			(7.605)			(8.238)
BminRAT x Period 2			9.065			5.665
			(9.887)			(14.551)
NBminRAT x Period 2			12.183			9.650
			(10.501)			(13.094)
RAT x Period 3			18.702**			19.356**
			(7.722)			(8.523)
BminRAT x Period 3			13.573			12.969
			(9.878)			(14.506)
NBminRAT x Period 3			19.034*			20.756
			(10.661)			(13.167)
RAT x Period 4			28.915***			28.810***
			(7.578)			(8.719)
BminRAT x Period 4			21.802**			19.376
			(9.695)			(14.487)
NBminRAT x Period 4			29.003***			32.105**
			(10.688)			(13.349)
RAT x Period 5			40.671***			47.672***
			(7.455)			(8.295)
BminRAT x Period 5			31.262***			35.092**
			(9.427)			(13.790)
NBminRAT x Period 5			39.484***			48.114***
			(10.569)			(12.965)
Constant	38.095***	35.578***	47.930***	31.427***	29.480***	42.393***
	(3.959)	(2.947)	(4.135)	(4.677)	(3.572)	(4.960)
Observations	116	580	580	116	580	580
R^2	0.119	0.111	0.165	0.146	0.132	0.179
Adjusted R^2	0.095	0.100	0.137	0.124	0.121	0.151

Note: OLS regressions. Robust standard errors in parentheses. We use participants' average cooperation rate per group as dependent variable. The explanatory variables in column 1 are indicator variables for the treatments. Observations are aggregated at the phase and period level, i.e., we have one observation for each of the 116 groups in our experiment. Column 2 contains indicator variables for treatments and periods. Observations are aggregated at the phase level, i.e., we have five observations per group and 580 in total. Column 3 contains the interaction of indicator variables for treatments with indicators for periods. Column 4 contains the regression results of column 1 for Phase V only. *RAT*: indicator for the ratcheting treatment, *BminRAT*: indicator for the ratcheting treatment with binding minimum contribution phase, *NBminRAT*: indicator for the ratcheting treatment with non-binding minimum contribution phase, *period 2 - 5*: indicator for Period 2 to 5. * p<0.10, ** p<0.05, and *** p<0.01.

Table C.3: Ex-post Wald tests for differences between treatments

	H_0	F-value	p-value
Panel A. Over all phases			
	RAT – BminRAT = 0	15.312	<0.001
	RAT – NBminRAT = 0	1.897	0.171
	BminRAT – NBminRAT = 0	3.277	0.073
Panel B. Phase V			
	RAT – BminRAT = 0	15.118	<0.001
	RAT – NBminRAT = 0	1.689	0.196
	BminRAT – NBminRAT = 0	4.506	0.036

Note: Panel A (B) shows the results of ex-post Wald tests for differences in coefficients based on OLS regressions in Table C.2, column 1. *RAT*: indicator for the ratcheting treatment, *BminRAT*: indicator for the ratcheting treatment with binding minimum contribution, *NBminRAT*: indicator for the ratcheting treatment with non-binding minimum contribution.

Table C.4: Treatment effects per phase

	Dependent Variable: Cooperation rate (in percent)				
	Phase I	Phase II	Phase III	Phase IV	Phase V
	(1)	(2)	(3)	(4)	(5)
RAT	-11.403**	-16.752***	-13.095**	-14.538**	-12.364**
	(5.511)	(6.063)	(5.916)	(6.303)	(5.667)
BminRAT	-4.197	-4.329	17.768*	23.265***	23.364**
	(8.033)	(7.945)	(9.703)	(8.605)	(9.802)
NBminRAT	2.542	-7.226	-7.159	-5.594	-1.361
	(8.403)	(8.739)	(8.697)	(8.259)	(9.129)
Constant	46.106***	42.359***	35.644***	34.938***	31.427***
	(4.022)	(4.344)	(4.468)	(4.665)	(4.677)
Observations	116	116	116	116	116
R^2	0.039	0.056	0.116	0.170	0.146
Adjusted R^2	0.013	0.031	0.092	0.148	0.124

Note: OLS regressions. Robust standard errors in parentheses. We use participants' average cooperation rate per group as dependent variable. The explanatory variables are indicator variables for the treatments. We estimate the regressions separately for all five phases, i.e., Phase I – V. Observations per phase are aggregated at the period level, i.e., we have one observation for each of the 116 groups in our experiment. * p<0.10, ** p<0.05, and *** p<0.01.

Table C.5: Decomposed cooperation rates in BminRAT and NBminRAT by phase

	Cooperation rate	**Minimum cooperation rate**	**Excess cooperation rate**
Panel A. Phase I			
BminRAT	34.379***	19.272***	15.106***
	(6.650)	(6.802)	(2.737)
NBminRAT	40.370***	22.296***	18.074**
	(7.841)	(7.891)	(7.616)
Difference	-5.992	-3.024	-2.968
	(10.281)	(10.418)	(8.093)
Panel B. Phase II			
BminRAT	31.288***	17.515**	13.773***
	(6.774)	(7.100)	(4.216)
NBminRAT	25.056***	23.704***	1.352
	(7.370)	(9.211)	(7.798)
Difference	6.232	-6.189	12.421
	(10.010)	(11.630)	(8.865)
Panel C. Phase III			
BminRAT	48.955***	41.697***	7.258***
	(9.3164)	(10.669)	(2.395)
NBminRAT	16.796**	12.444	4.352
	(7.243)	(7.636)	(6.253)
Difference	32.158***	29.255**	2.906
	(11.800)	(13.120)	(6.696)
Panel D. Phase IV			
BminRAT	54.061***	43.212***	10.848***
	(7.795)	(9.587)	(3.390)
NBminRAT	20.019***	18.519**	1.5
	(6.440)	(8.487)	(6.661)
Difference	34.042***	24.694*	9.348
	(10.112)	(12.804)	(7.474)
Panel E. Phase V			
BminRAT	51.136***	38.909***	12.227***
	(9.085)	(11.206)	(3.267)
NBminRAT	18.907**	27.778***	-8.870
	(7.508)	(9.121)	(6.280)
Difference	32.229***	11.131	21.098***
	(11.786)	(14.449)	(7.078)
Panel F. Overall			
BminRAT	43.964***	32.121***	11.842***
	(5.736)	(6.633)	(2.192)
NBminRAT	24.23***	20.948***	3.282
	(6.114)	(6.778)	(4.634)
Difference	19.734**	11.173	8.561
	(8.384)	(9.484)	(5.126)

Note: Cooperation rates per treatment in first period of each phase decomposed into the minimum and excess cooperation rates, separately for Phase I (Panel A), Phase II (Panel B), Phase III (Panel C), Phase IV (Panel D), Phase V (Panel E), and overall (Panel F). * p<0.10, ** p<0.05, and *** p<0.01.

Table C.6: Effect of non-compliance on proposed minimum cooperation rates

Overall	Phase II	Phase III	Phase IV	Phase V
-4.231***	-1.091	-3.453	-4.929	-7.333
(1.480)	(3.462)	(3.700)	(3.129)	(5.660)

Note: We only use observations from *NBminRAT*. We use participants' individual proposals for the collective minimum cooperation rate in Phases II to V as dependent variable. As independent variable we use the number of other group members who provide a cooperation rate below the collective minimum cooperation rate in Period 1 of the previous phase, i.e., a count variable ranging from 0 (only Compliers) to 3 (no Compliers). Robust standard errors are clustered on subject level. * p<0.10, ** p<0.05, and *** p<0.01.

Table C.7: Effects of non-compliance on minimum and excess cooperation rates for Initial Compliers and Initial Non-Compliers

	Overall	Phase II	Phase III	Phase IV	Phase V
Panel A. *Initial Compliers*					
Minimum cooperation rate	-3.701***	-2.333	-2.604	-4.737	-4.218
	(1.416)	(6.939)	(5.256)	(3.765)	(4.601)
Excess cooperation rate	-11.279***	-7.571	-6.658	-10.120***	-16.427***
	(3.072)	(8.629)	(5.0582)	(3.802)	(4.589)
Panel B. *Initial Non-Compliers*					
Minimum cooperation rate	-2.993	7.639	-8.625	3.185	-36.825**
	(6.364)	(7.901)	(13.083)	(8.603)	(17.279)
Excess cooperation rate	-0.647	-8.767	-0.130	6.011	0.899
	(1.734)	(5.970)	(3.092)	(10.222)	(15.202)

Appendix D Experimental instructions

In this section of the appendix, we reproduce the instructions used in our experiment. First, we present the instructions used in *BASE* and highlight, using boxes, where and how instructions in *RAT* differ. Second, we present instructions for *BminRAT* and highlight the differences for *NBminRAT*. For the sake of simplicity, we translated the original instructions from German to English. Instructions in German are available upon request from the authors.

Appendix D.1 Instructions for *BASE* and *RAT*

Welcome to Magdeburg Experimental Laboratory MAXLAB!

Please read the instructions carefully and contact us if you have any questions. To do this, please use our chat, which is displayed at the bottom right of the page.
In the experiment you are now participating in, you can earn money depending on your decisions and the decisions of your co-players. Your payment from the experiment is calculated in Labor Dollars (LD), where the exchange rate between Euro and LD is 1:100, i.e., 100 LD equals 1 Euro. You make your decisions in the experiment anonymously. Only the experimenters will know your identity, and your details will of course be treated as strictly confidential.

Rules of the experiment
A total of four players take part in the experiment, i.e., three other players besides you. The three participants you interact with are the same throughout the course of the experiment.
The experiment comprises five phases. In each of the five phases, you play the same game. Every play consists of five periods. Thus, in total, you play 5 x 5 = 25 periods. At the start of each period, you and your three fellow players each receive an initial endowment of 100 LD. Thus, in the course of five periods, i.e., per phase, you receive 500 LD in total.
Your task, and the task of your fellow players, consists in deciding how many LD you want to contribute to a joint project. Your contribution can vary between 0 and 100 LD (only integers) in period 1.

Your task, and the task of your fellow players, consists in deciding how many LD you want to contribute to a joint project. Your contribution can vary between 0 and 100 LD (only integers) in period 1. In all other periods, your contribution needs to be at least as high as in the previous period. The maximum contribution is 100 LD.

Your payoff in periods 1 through 5 is as follows:

$$= 4.4(100 - your\ contribution) - 0.02(100 - your\ contribution)^2$$
$$+(your\ contribution + contributions\ of\ the\ other\ three\ players) - 100$$

That is, for example, if all the other three players contribute on average 30 LD to the project in each period and you contribute 90 LD, your payoff will be:

$$= 4.4(100 - 90) - 0.02(100 - 90)^2 + (90 + 3 * 30) - 100 = 44 - 2 + 180 - 100 = 122$$

Conversely, if all other players contribute an average of 30 LD and you contribute nothing, your payoff is:

$$= 4.4(100 - 0) - 0.02(100 - 0)^2 + (3 * 30) - 100 = 440 - 200 + 90 - 100 = 230$$

To make it easier for you to calculate your payoff, you will find our Help Desk on the right-hand side of the screen. The Help Desk includes a payoff table as well as a payoff simulator. In the payoff table you can set the average contribution of all other players (column) and your contribution (row) per period (each in increments of 5). In the corresponding cell of the table you will then find your payoff per period in LD. We also explain how you can use the payoff table in a short video that is displayed below the table. In addition, you will find a payoff simulator in the help desk. In the payoff simulator you can enter the average contribution of all other players and your contribution per period. The payoff simulator then calculates your payoff.
At the end of the game, you will receive the payoff from one of the five phases in euros (according to the conversion rate of 100 LD = 1 euro). The phase that is paid out is determined randomly. Therefore, you should behave in every period of a stage as if it were payoff relevant. At the beginning there is a short trial phase with three periods (periods 0 to 2), which is not relevant to the payoff.

Please contact us if you have a question. Please use our chat, which is displayed at the bottom right of the page. When you have finished reading the text and have no questions, please click Next.

Control questions
If you have read the instructions and have no questions, please answer the following control questions. To make the calculations easier for you, you will find our Help Desk on the right-hand side of the screen. The Help Desk once again contains the instructions as well as the payoff table and the payoff simulator.

Question 1. Assuming your contribution to the project amounts to 20 LD while the average contribution of all other players is 50 LD: what is your payoff (in LD) in that period? My payoff is: _______

Question 2. Assuming your contribution to the project amounts to 60 LD while the average contribution of all other players is 20 LD: what is your payoff (in LD) in that period? My payoff is: _______

Question 3. Assuming that the average contribution of all other players is 15 LD: with which of the following contributions can you achieve the highest payoff in that period (please tick)?

O 5
O 10
O 15
O 20

Question 4. Assuming that you want to maximize your payoff: does it make sense to make no contribution (i.e. zero) to the project?

O Yes
O No

Question 5. Assuming that all players choose to make the same contribution: which of the following contributions leads to the highest total payoff to all players in a period (please tick)?

O 0
O 50
O 70
O 90
O 100

Question 6. Which rule applies to your payoff?

- O One period is drawn from the 5x5=25 periods and paid out.
- O One of the five phases, consisting of five periods, is drawn and paid out.
- O All 5x5=25 periods are paid out.

Question 7. Assuming that you have contributed 20 LD to the joint project in period 1 of a phase: how much do you need to contribute at least to the joint project in period 2? ____ LD

Question 8. Assuming that you have contributed 20 LD to the joint project in period 1 of a phase: how much do you need to contribute at least to the joint project in period 5, i.e., in the last period of the phase? ____ LD

Please contact us if you have a question. Please use our chat, which is displayed at the bottom right of the page. If you have answered all the control questions correctly, please click Next.

Appendix D.2 Instructions for *BminRAT* and *NBminRAT*

Welcome to the virtual Magdeburg experimental laboratory MaXLab!

Please read the instructions carefully and contact us if you have any questions. To do this, please use our chat, which is displayed at the bottom right of the page.
In the experiment you are now participating in, you can earn money depending on your decisions and the decisions of your co-players. Your payment from the experiment is calculated in Labor Dollars (LD), where the exchange rate between Euro and LD is 1:100, i.e., 100 LD equals 1 Euro. You make your decisions in the experiment anonymously. Only the experimenters will know your identity, and your details will of course be treated as strictly confidential.

Rules of the experiment
A total of four players take part in the experiment, i.e., three other players besides you. The three participants you interact with are the same throughout the course of the experiment.

General process
The experiment consists of five phases. In each of the five phases you always play the same game. Each of the games consists of six periods (periods 0 to 5). The following applies here:
In period 0, you always decide together with your group members on a collective minimum contribution that each member of your group must at least contribute to a joint project in period 1.

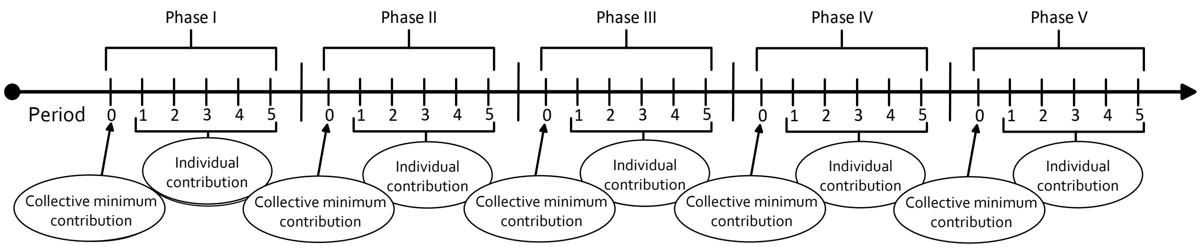
In period 0, you always decide together with your group members on a collective minimum contribution that each member of your group should at least contribute to a joint project in period 1. You can then decide to what extent you follow the suggestion.

From period 1 you then decide on your individual contribution to the joint project.

In period 1, your individual contribution must be at least as high as the collective minimum contribution that you agreed on in your group in period 0.

In period 1, your individual contribution should be at least as high as the collective minimum contribution that you agreed on in your group in period 0.

In all further periods (periods 2 to 5) your individual contribution must be at least as high as your individual contribution in the previous period.
The figure below shows the course of the experiment.



Details of the experiment
Collective minimum contribution: In period 0, you and your group members decide on the collective minimum contribution that each group member must contribute to the joint project in period 1. To do this, you first suggest the minimum contribution, q_{min}, which, from your perspective, every player in period 1 must contribute to the joint project. The other players in your group also make a corresponding suggestion at the same time. Then the minimum of the four individual proposals, $min\ (q_{min})$, is selected as the collective minimum contribution.

Collective minimum contribution: In period 0, you and your group members decide on the collective minimum contribution that each group member should contribute to the joint project in period 1. To do this, you first suggest the minimum contribution, q_{min}, which, from your perspective, every player in period 1 should contribute to the joint project. The other players in your group also make a corresponding suggestion at the same time. Then the minimum of the four individual proposals, $min\ (q_{min})$, is selected as the non-binding collective minimum contribution.

Individual contributions: From period 1, you and your three co-players each receive an initial endowment of 100 LD at the beginning of each period. So, over the course of five periods, you will be credited a total of 500 LD per phase. Your task, as well as the task of your co-players, consists in each of the periods to decide how many LD you contribute to a joint project.
In period 1, your individual contribution, q, has to be at least as high as the collective minimum contribution, $q \geq min\ (q_{min})$.

In period 1, your individual contribution, q, should be at least as high as the collective minimum contribution, $q \geq min\ (q_{min})$. You can then decide to what extent you follow the suggestion.

In all further periods (periods 2 to 5) your individual contribution must be at least as high as your individual contribution in the previous period. The maximum contribution is 100 LD (integers only).
Your payoff in periods 1 through 5 is as follows:

$$= 4.4(100 - your\ contribution) - 0.02(100 - your\ contribution)^2$$
$$+ (your\ contribution + contributions\ of\ other\ players) - 100$$

That is, if, for example, all other three players contribute an average of 30 LD per period and you contribute 90 LD to the project, then your payoff is:

$$= 4.4(100 - 90) - 0.02(100 - 90)^2 + (90 + 3 * 30) - 100 = 44 - 2 + 180 - 100 = 122$$

Conversely, if all other players contribute an average of 30 LD and you contribute nothing, your payoff is:

$$= 4.4(100 - 0) - 0.02(100 - 0)^2 + (0 + 3 * 30) - 100 = 440 - 200 + 90 - 100 = 230$$

To make it easier for you to calculate your payoff, you will find our Help Desk on the right-hand side of the screen. The Help Desk includes a payoff table as well as a payoff simulator. In the payoff table you can set the average contribution of all other players (column) and your contribution (row) per period (each in increments of 5). In the corresponding cell of the table you will then find your payoff per period in LD. We also explain how you can use the payoff table in a short video that is displayed below the table. In addition, you will find a payoff simulator in the help desk. In the payoff simulator you can enter the average contribution of all other players and your contribution per period. The payoff simulator then calculates your payoff.

At the end of the game, you will receive the payoff from one of the five phases in euros (according to the conversion rate of 100 LD = 1 euro). The phase that is paid out is determined randomly. Therefore, you should behave in every period of a stage as if it were payoff relevant. At the beginning there is a short trial phase with three periods (periods 0 to 2), which is not relevant to the payoff.
Please contact us if you have a question. Please use our chat, which is displayed at the bottom right of the page. When you have finished reading the text and have no questions, please click Next.

Control questions
If you have read the instructions and have no questions, please answer the following control questions. To make the calculations easier for you, you will find our Help Desk on the right-hand side of the screen. The Help Desk once again contains the instructions as well as the payoff table and the payoff simulator.

Question 1. Suppose the average contribution of all other players is 50 LD. Your contribution to the project is 20 LD. What is your payoff in this period?
My payoff (in LD) is: _____

Question 2. Suppose the average contribution of all other players is 20 LD. Your contribution to the project is 60 LD. What is your payoff in this period?
My payout (in LD) is: _____

Question 3. Assuming the average contribution from all other players is 15 LD, which of the following contributions will yield the highest payoff (please click)?

O 5
O 10
O 15
O 20

Question 4. Assuming you want to maximize your payoff, does it make sense to make no (i.e. zero) contribution to the project?

O Yes
O No

Question 5. Assuming all players choose the same contribution, which of the following contributions has the highest total payoff for all players (please click)?

O 0
O 50
O 70
O 90
O 100

Question 6. What rule applies to your payment?

O One period is drawn from the 5x5=25 periods and paid out.
O One of the five phases, consisting of five periods, is drawn and paid out.
O All 5x5=25 periods are paid out.

Question 7. Assuming you contributed 20 LD to the joint project in period 1 of a phase, what is the minimum amount you must contribute to the joint project in period 2 of the phase (in LD)? _____

Question 8. Suppose you contributed 20 LD to the joint project in period 1 of a phase. What is the minimum amount you must contribute to the joint project (in LD) in period 5, i.e., the last round of the phase, if you always contribute as little as possible? _____

Question 9. Suppose that in period 0, the four players in a group declared 10, 30, 50, and 70 LD for the collective minimum contribution in period 1, respectively. How high must your individual contribution to the joint project in period 1 be at least?
Greater or equal (in LD) _____

Please contact us if you have a question. Please use our chat, which is displayed at the bottom right of the page. If you have answered all the control questions correctly, please click Next.