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The impact of burden sharing rules on the voluntary provision of public goods

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1. Introduction

The provision of public goods often faces the problem that agents need to voluntarily decide on their own contributions or – alternatively – have to agree upon some desired provision level of the public good in combination with a specific burden sharing rule. This challenge is particularly demanding when interests differ among players due to heterogeneous preferences. Examples reach from international climate policy (e.g., Nordhaus, 2010) to the provision of local public goods like maintaining infrastructure for irrigation (e.g., Bardhan, 2000; Dayton-Johnson, 2000a,b). While strong free-riding incentives prevent a pure voluntary and uncoordinated solution, both the level of the provision of a public good and the distribution of the burden are mostly subject to intense debate.

In this paper, we investigate how burden sharing rules impact the provision level of a public good that all agents voluntarily accept. We focus on different rule-based contribution mechanisms that are based on the principle of the smallest common denominator: all agents can suggest a minimum provision level of the public good that is allocated across agents according

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to some predetermined rule. The minimum of all proposals, i.e. the smallest common denominator, then takes effect and creates a lower bound for the individual contribution levels.[1]

This approach reflects many real world institutional arrangements that involve either a simultaneous or a sequential choice of the provision goal and the burden sharing rule. For the climate policy example, a pre-negotiated rule, e.g. using uniform obligations among countries (Barrett, 2003), may be particularly beneficial in reducing negotiation costs when the total target changes over time. Since each participating country needs to sign and ratify the agreement, the player with the smallest proposal is pivotal. Countries can, however, voluntarily go beyond their obligations. Similar burden sharing rules can be applied to individual decisions on voluntary public good provision (Dayton-Johnson, 2000a,b). In the literature, the interaction of burden sharing has been discussed within the concept of Lindahl prices (Silvestre, 1984; Sato, 1987), where the outcome is given when no agent would desire reducing the public-good provision simultaneously with his own individual contribution to the public good (see van den Nouweland et al., 2002; Bilodeau and Gravel, 2004). We contribute to the literature by experimentally comparing the ability of different rule-based contribution schemes to overcome the inefficiency in public good provision.

Our paper relates to the vibrant literature on the voluntary provision of public goods. Orzen (2008) and Dannenberg et al. (2014) have shown the benefits from such a smallest common denominator rule when agents are homogeneous. It may not be surprising that these authors find this mechanism to allow groups to reach large provision levels, thereby generating substantial welfare gains relative to the voluntary contribution mechanism, as players have a weakly dominant strategy to suggest an efficient provision and the only fair burden sharing rule allocates the same burden to all players. However, cooperation in many settings faces the challenge of substantially differing interests, for example due to different wealth or costs and benefits from the public good. Our paper explores the performance of rule-based contribution schemes for heterogeneous agents. We focus on differences in the agents' benefits from the public good.

There is a significant literature on voluntary public good provision when players are heterogeneous. Many papers concentrate on endowment heterogeneity. Ledyard (1995) and Zelmer (2003) each review several experimental studies and find a negative impact of endowment heterogeneity on contributions.[2] Spraggon and Oxoby (2009) show endowment effects to be sensitive to the endowments' origin. Ledyard (1995) and Zelmer (2003) summarize findings that higher marginal per capita returns (MPCR) increase contributions. Relative to homogenous groups of identical MPCR, Fisher et al. (1995) report tendencies of low-type players (MPCR = 0.3) contributing more and high-type players (MPCR = 0.7) contributing less when combined in one heterogeneous group. Tan (2008) find that heterogeneity with respect to contributing costs lowers cooperation. Reuben and Riedl (2013) show that heterogeneities in endowments or benefits do not alter decision behavior if no punishment options exist, while with punishment contributions are proportional to endowments or respectively to the ratio of marginal benefits. Fellner et al. (2011) investigate the impact of productivity isolated from the costs of contribution. They report that information about heterogeneity increases cooperation but alters contribution norms. While less information leads to more equal contributions, subjects focus on group efficiency in case of full information. Considering an endogenous coalition formation setting, McGinty et al. (2012) focus on different distribution rules for coalition payoffs among heterogeneous players and find that efficiency substantially depends on the rule for division of coalitions' benefits.

In this paper, we introduce heterogeneity with respect to the benefits from a public good in a linear four-person game. Each group consists of two high-type players (MPCR = 0.7) and two low-type players (MPCR = 0.3). We compare the traditional *VCM* with four other treatments that are based on the smallest common denominator rule, but differ in the implemented burden sharing rule: (i) two variants of equal minimum contribution requirements for all players, (ii) separated minimum levels for low- and high-type players, and (iii) a burden sharing rule aiming at equalizing payoffs of all players. The first rule equally distributes the contribution obligation on all players. We thereby can study the performance of an equal contribution rule (Orzen, 2008; Dannenberg et al., 2014) to a heterogeneous player setting. Here, the different types of players can only implicitly differentiate their burden by voluntarily contributing more than required. The other two rules make this differentiation of burdens more explicit: The second rule allows both types of players to separately implement minimum contribution requirements that are only binding for players of their own type. This treatment is inspired by proposals in international climate policy negotiations to have small agreements among more homogeneous players rather than creating the problem of complicated discussion on burden sharing rules when all countries try to agree on a comprehensive treaty as in the Kyoto process (e.g., Olmstead and Stavins, 2006; Edenhofer et al., 2013). It also alludes to recent findings that public good provision may benefit from endogenously choosing institutional features (e.g., Kosfeld et al., 2009) as the differentiation of burdens based on the separate minimum requirements is endogenously determined. The last rule exogenously differentiates the burden with the goal of equalizing payoffs. This rule is inspired by recent findings that behavior by some individuals

[1] The implementation of the smallest common denominator bears similarities to "weakest link" games (e.g., Harrison and Hirshleifer, 1989; Cornes and Hartley, 2007). However, while in weakest link games, provision exceeding the implemented minimum (i.e., weakest link) is costly to agents, making a minimum proposal larger than the implemented smallest common denominator comes at no costs, as agents decide about the actual contribution level in the second stage.

[2] van Dijk et al. (2002) and Cherry et al. (2005) as well as Anderson et al. (2008) also confirm the negative endowment effect. In contrast, Chan et al. (1996, 1999) and Buckley and Croson (2006) show potential positive effects. Recent studies on this topic include Sadrieh and Verbon (2006), Koukoumelis et al. (2010) and Georgantzis and Proestakis (2011).

may be explained by inequality aversion (e.g., Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000; Charness and Rabin, 2002).

Our results indicate that all rule-based contribution schemes significantly increase both payoff levels relative to the *VCM*. Interestingly, the equal-payoff rule maximizes payoffs to both player types, i.e. it payoff-dominates all other rules. Explicitly addressing redistribution among heterogeneous players by equalizing payoffs in a setting where all players make proposals on the total provision level performs best due to substantially higher contributions from high-type players. This holds in particular relative to the scheme where high- and low-type players separately can determine their minimum contribution: here, low-type agents end up contributing at the same rate as in the equal-payoff treatment while, in contrast to standard theoretical predictions, high-type agents fail to reach similar contribution levels. This result thereby indicates an important caveat of the smallest common denominator rule: differently from Orzen (2008) and Dannenberg et al. (2014), even homogeneous agents may fail to achieve efficient outcomes in presence of players with other characteristics. We therefore find a superiority of appropriately designed rule-based contribution schemes that involve all players rather than having separate schemes for players of the same type.

The remainder of the paper is organized as follows. Section 2 derives predictions for our experiment within a theoretical framework that allows players to be inequality-averse. The experimental design is described in Section 3. We discuss our results in Section 4, before concluding in Section 5.

2. Experimental treatments and theoretical predictions

In our experiment, we consider different institutions by which agents may decide upon the provision of a public good. The payoff structure in all treatments is given by a linear public good game. That is, the payoff to player i is given by

$$\pi_i = e - q_i + b_i Q \tag{1}$$

where e denotes the initial endowment, q_i the individual contribution, b_i the marginal benefit from the public good to player i, and $Q = \sum_{j=1}^{n} q_j$ the total provision level of the public good. Players differ with respect to their marginal benefits from the public good only. As standard, we assume that $b_i < 1$ and $\sum_{j=1}^{n} b_j > 1$. In our experiment, we consider groups of four players ($n = 4$) that consist of two low-type players ($b_L = 0.3$) and two high-type players ($b_H = 0.7$). The endowment is given by $e = 20$ such that $q_i \in [0{,}20]$.

In the following, we first define the different institutions that will be investigated in our experiment, before providing a discussion of the theoretical predictions. In addition to the reference case of *voluntary contribution mechanism* (*VCM*) where individuals simultaneously choose their contribution levels q_i, we consider rule-based contribution schemes where players in a first stage are requested to make suggestions either for individual minimum contributions or for a total provision level whose costs are then allocated across the agents according to differing burden sharing rules. The suggestions in the first stage lead to a binding minimum contribution for each player in the second stage ($q_i \geq q_i^{\min}$).

2.1. Common individual minimum contribution mechanism (eqcont_q)

We first consider a setting in which all subjects first simultaneously suggest a common individual minimum contribution level for all players. After these minimum proposals $q_i^{\min}$ are received from all agents, this rule requires all four players to provide at least the smallest suggested level, i.e. $q_i \geq q^{\min} = \min_j q_j^{\min}$. The notation is chosen to reflect that proposals are made for individual contribution levels (“*q*”) under a rule that implements *eq*ual minimum *cont*ributions.

2.2. Separate individual minimum contribution mechanism (sepcont_q)

In the next treatment, we consider a modification to *eqcont_q* in which the high- and low-type players may suggest an individual minimum contribution level that applies only to their own type. This treatment incorporates the idea that a forced equal contribution obligation that is implicitly present in *eqcont_q* may not be acceptable when agents are heterogeneous. Rather, differentiated obligations for the respective player types are possible. That is, low-type players agree on their own binding minimum level $q_L^{\min} = \min_{j \in LOW} q_j^{\min}$ and high-type players choose $q_H^{\min} = \min_{j \in HIGH} q_j^{\min}$. Here the notation reflects that two *sep*arate minimum *cont*ribution levels are implemented for the two types.

The two treatments *eqcont_q* and *sepcont_q* thereby rely on a minimum mechanism in which players can suggest an *individual* contribution level.

We next consider contributions schemes in which all players suggest a total provision level Q that is distributed across agents to a specific rule such that $q_i \geq \alpha_i Q$ where $\sum_i \alpha_i = 1$. We define such schemes as follows: In a first step, each agent can suggest a total provision level Q_i. In a second step, the minimum $Q^{\min} = \min_j Q_j$ of the suggested levels is decisive for contributions such that $q_i \geq \alpha_i Q^{\min}$.

2.3. Equal contribution treatment (eqcont_Q)

In our experiment, we introduce a treatment *eqcont_Q* with $\alpha_i = 1/n$. The strategic features of this rule coincide with *eqcont_q*. However, we implement this treatment in order to control for framing effects: while players in *eqcont_q* suggest an individual minimum, they propose a group contribution level in *eqcont_Q* that is then equally distributed across players.

2.4. Equal payoff treatment (eqpay)

We finally consider a burden sharing rule, *eqpay*, that is motivated by reaching *eq*ual *pay*offs. A large literature (e.g., Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000) has considered inequality aversion as a motivational driver in experiments. We therefore implement a rule for which the α_i values are determined such that the payoff $\pi_i = e + (b_i - \alpha_i)Q$ is identical for all players i. In general, this implies that $(b_i - \alpha_i)Q = (b_j - \alpha_j)Q$ for all i,j, such that $n(b_i - \alpha_i) = \sum_j (b_j - \alpha_j)$ or – equivalently

$$\alpha_i = b_i - \frac{1}{n}\left(\sum_j b_j - 1\right)$$

which in our experiment would require $\alpha_L = 0.05 = 0.3 - (2-1)/4$ and $\alpha_H = 0.45 = 0.7 - (2-1)/4$. Naturally, high-types can maximally contribute their endowment. As such, the individual minimum requirements can only equalize payoffs if $\alpha_H Q^{\min} \le e$, or $Q^{\min} \le 20/0.45 = 44.4$. For $Q^{\min} > 20/0.45$, we distribute the burden such that high-type players are required to contribute all their endowment, while the low-type players receive a minimum commitment of $(Q^{\min} - 40)/2$. Note, however, that even if the minimum requirement equalizes payoffs, inequalities may arise due to voluntary contributions beyond the required minimum.

2.5. Predictions

We now derive predictions for the described treatments. We allow for inequality aversion and use a simple specification inspired by Bolton and Ockenfels (2000). That is, we assume that agents compare their own to the average payoff of the whole group. Furthermore, we assume that agents are homogenous in their preference. Specifically, we assume that the utility of player i is given by

$$u_i(\pi_i, \pi^a) = \pi_i - \alpha(\max[\pi^a - \pi_i, 0])^2 - \beta(\max[\pi_i - \pi^a, 0])^2$$

where $\pi^a = \sum_j \pi_j / n$ denotes the average payoff and $\alpha \ge 0$ ($\beta \ge 0$) reflects aversion to inequality when the agent is worse (better) off than the average person.[3] As described above, subjects were bound in the second stage to contribute $q_i \ge q_i^{\min}$ where $q_i^{\min}$ was determined based on the proposals in the first stage. We first consider the second stage in order to explore to what extent agents may go beyond the minimum requirement.

The first-order condition reads

$$\frac{du_i}{dq_i} = -1 + b_i - 2\alpha \max[\pi^a - \pi_i, 0]\left(\frac{n-1}{n} - (b_i - b^a)\right)$$
$$+2\beta \max[\pi_i - \pi^a, 0]\left(\frac{n-1}{n} - (b_i - b^a)\right)\begin{cases} \le 0 & \text{if } q_i = q_i^{\min} \\ = 0 & \text{if } q_i^{\min} < q_i < e \\ \ge 0 & \text{if } q_i = e \end{cases}. \qquad (2)$$

Here, $b^a = \sum_j b_j / n$. The term in the bracket is positive for all agents since $(n-1)/n - (b_i - b^a) \ge (n-1)/n - (b_H - b_L)/2 \ge (n-1)/n - b_H/2 > 0$ is always satisfied due to the assumed public good property $b_i < 1$.[4] Hence, no agent with $\pi_i < \pi^a$ would voluntarily contribute more than required. In order to simplify the following exposition of the predictions, we use the exact parameter values used in our experimental design.[5]

We further concentrate on equilibria in which both players of the same type contribute the same amount, denoted by q_L for both low-types and q_H for both high-type players. The resulting payoffs are denoted by π_L and π_H.

[3] Using a model based on Fehr and Schmidt (1999) would generate similar results, but – due to its linearity conditions – generates corner solutions that do not appear to reflect the empirical findings.

[4] The brackets take values 0.55 for high-types and 0.95 for low-types under our specification ($b_H = 0.7$, $b_L = 0.3$, $b_a = 0.5$).

[5] The predictions in part depend on the difference between the MPCR for high and low types ($b_H - b_L$). For example, multiple equilibria may exist even in the VCM if the difference is larger than 0.5: if no other player contributes, contributions by a player would decrease his own payoff, but introduce inequality such that zero contributions is always an equilibrium. If, however, both high type players contribute their full endowment, they are still better off than the low type players and therefore this full contribution may establish an equilibrium as well if inequality aversion is sufficiently large. Qualitatively, our predictions are robust within the range $b_H - b_L < 0.5$.

We first consider high-type players and explore when they may contribute above the minimum requirement. As this can only hold true if $\pi_H > \pi_L$, and noting that $2(\pi^a - \pi_L) = \pi_H - \pi_L$, we can rewrite (2) as

$$-0.3 + 0.55\beta(\pi_H - \pi_L) = -0.3 + 0.55\beta(0.4 \times 2(q_H + q_L) + q_L - q_H) \leq 0$$

and, with (1), immediately obtain

$$q_H \geq 9q_L - \frac{0.3}{0.2 \times 0.55\beta}.$$

Taking into account the maximum contribution being 20, we obtain as optimal provision level:

$$q_H^*(q_L^{\min}, q_H^{\min}) = \max\left[q_H^{\min}, \min\left[20, 9q_L^{\min} - \frac{1.5}{0.55\beta}\right]\right]. \tag{3}$$

Analogously, we can derive the optimal second stage contribution for the low-type player by using (2) for $\pi_L > \pi_H$:

$$-0.7 + 0.95\beta(-0.4 \times 2(q_H + q_L) - q_L + q_H) \leq 0$$

such that we obtain as optimal choice:

$$q_L^*(q_L^{\min}, q_H^{\min}) = \max\left[q_L^{\min}, \frac{1}{9}q_H^{\min} - \frac{3.5}{0.95 \times 9\beta}\right]. \tag{4}$$

That is, the players may voluntarily contribute more than required if their inequality aversion is sufficiently large and the minimum requirement prescribes commitment levels which make the respective type of player better off in terms of payoff than the other type.

2.5.1. Predictions for VCM

Note that in the *VCM* ($q_L^{\min} = q_H^{\min} = 0$), zero contribution result from (3) and (4). No player has an incentive to deviate as this would both lower the own payoff and introduce inequality.

We now turn to the first stage under the respective minimum contribution schemes.

2.5.2. Predictions for minimum contribution mechanism (eqcont_q, eqcont_Q)

For both common minimum contribution mechanisms, $q_L^{\min} = q_H^{\min} = q^{\min}$, such that high-type agents have a larger payoff than low-types ($q_L^* = q^{\min}$) and need to consider their potential impact of the first stage choice on the provision levels of all other players. That is, if the proposal is binding it impacts the contribution decisions of both high-type and both low-type agents:

$$\begin{aligned}\frac{du_H}{dq^{\min}} &= \frac{dq_H^*}{dq^{\min}} + b_H\left(2\frac{dq_H^*}{dq^{\min}} + 2\underbrace{\frac{dq_L^*}{dq^{\min}}}_{=1}\right) - \beta\frac{\pi_H - \pi_L}{2}\left(-\left(\frac{dq_H^*}{dq^{\min}} - \underbrace{\frac{dq_L^*}{dq^{\min}}}_{-1}\right)\right.\\ &\left.+(b_H - b_L)\left(2\frac{dq_H^*}{dq^{\min}} + 2\underbrace{\frac{dq_L^*}{dq^{\min}}}_{=1}\right)\right) = 0.4\frac{dq_H^*}{dq^{\min}} + 1.4 - \beta(\pi_H - \pi_L)\left(0.9 - .1\frac{dq_H^*}{dq^{\min}}\right).\end{aligned}$$

This expression is clearly positive for small levels of inequality aversion, such that agents have a weakly dominant strategy to suggest the maximum contribution level, i.e. $q^{\min} = 20$ in *eqcont_q* and $Q^{\min} = 80$ in *eqcont_Q*. If β is sufficiently large, however, high-type players may only desire to increase the minimum proposal as long as this allows them to voluntarily contribute more (i.e. being in the range where $dq_H^*/dq^{\min} = 9$), i.e. $20 \geq q_H^* = 9q^{\min} - 1.5/0.55\beta \geq q^{\min}$. Here, high-type players may choose the minimum to satisfy $q^{\min} = (20 + (1.5/0.55\beta))/9$.

For low-types, the marginal impact of the binding minimum on utility is analogously given by:

$$\frac{du_L}{dq^{\min}} = -0.4 + 0.6\frac{dq_H^*}{dq^{\min}} - \alpha(\pi_H - \pi_L)\left(0.9 - 0.1\frac{dq_H^*}{dq^{\min}}\right).$$

Again, they may refrain from suggesting a large binding minimum only if their own inequality aversion is sufficiently large. For example, if (high-type) agents are not inequality-averse ($dq_H^*/dq^{\min} = 1$), low-type agents benefit from an increase in the minimum requirement only if $\pi_H - \pi_L \leq 1/4\alpha$ which limits the proposal to $(b_H - b_L)4q^{\min} = 1/4\alpha$, or $q^{\min} = \min\left[20, 1/6.4\alpha\right]$.

Low-type agents will, however, also suggest a smaller minimum if they anticipate that the high-types will voluntarily provide more than required, i.e. if $q_H^* = 9q^{\min} - 1.5/0.55\beta \geq q^{\min}$. Here, they will benefit as long as $q_H^* \leq 20$, i.e. they will suggest $q^{\min} = \min\left[20, 20 + (1.5/0.55\beta)/9\right]$.

We therefore identified two reasons for low-types to suggest a lower binding minimum: (i) if they are inequality-averse themselves, they may want to hold back high-types to reduce the inequality in payoffs. (ii) If they anticipate high-types to be sufficiently inequality-averse, they may want to free-ride on the additional voluntary contributions by high-type players.

2.5.3. Predictions for separate individual minimum contribution mechanism (sepcont_q)

Let's first assume that low-types do not contribute and have chosen $q_L^{\min} = 0$. Then, the high-types would not voluntarily do more than they have agreed upon since this lowers their own payoff and also increases inequality. For any $q_H^{\min} > 0$, they have a smaller payoff than low-types. As such, an increase in the minimum proposal (if it is binding) impacts the contributions of both high-types and therefore changes utility according to:

$$\frac{du_H}{dq_H^{\min}} = -1 + 2b_H - \alpha\frac{\pi_L - \pi_H}{2}(1 - 2(b_H - b_L)) = 0.4 - 0.1\alpha(\pi_L - \pi_H) = 0.4 - 0.01\alpha q_H^{\min}.$$

where we used $2(\pi^a - \pi_H) = \pi_L - \pi_H$ to rewrite condition (2). Therefore, high-types have a weakly dominant strategy to propose and to coordinate on $q_H^{\min} = 20$ if their inequality aversion is small. If $\alpha > 2$, they reduce the proposal to $q_H^{\min} = 40/\alpha$.

Naturally, contributions by high-types generate inequality as low-types are now richer than high-types. If low-types are sufficiently inequality-averse, they may also start contributing and/or suggesting some positive minimum contribution level in order to decrease inequality as $q_L^* \geq (1/9)q_H^{\min} - (3.5/(0.95 \times 9\beta))$. We do not explicitly consider this case here as it qualitatively resembles the discussion above and may also be considered as relatively unlikely to occur since the level of inequality generated by contributions from high-type players is small. We note, however, that a situation with equal payoffs and positive contribution levels by all agents can never be sustained in equilibrium as then the marginal impact of contributions or minimum proposals on the inequality component in the utility function is zero such that – at the margin – the payoff component is decisive and leads to a reduction in contributions for low-type players.

2.5.4. Predictions for equal payoff treatment (eqpay)

The burden in this treatment is allocated such that payoffs are equalized as long as $Q^{\min} \leq (20/0.45) = 44.4$. Beyond this level, additional contributions would only stem from low-types such that their payoff would decrease and inequality would be introduced. Therefore, no low-type has an incentive to suggest a minimum larger than $Q^{\min} = 44.4$. Below this level, *all* agents' payoff is identical and increasing in $Q^{\min}$. Therefore, inequality aversion does not have an impact on the proposals such that we would expect $Q^{\min} = 44.4$ to be realized. This treatment therefore automatically leads to a better coordination between low- and high-type player which *sepcont_q* cannot achieve.

We can summarize the predictions under inequality aversion as follows:

- Independent of inequality aversion, players are predicted not to contribute in the *VCM*.
- When the institution implements a uniform minimum contribution level (*eqcont_Q*, *eqcont_q*), players are predicted to suggest the maximal contribution ($Q^{\min} = 80$ or $q^{\min} = 20$, respectively), if agents display no or small levels of inequality aversion. If high-type players are sufficiently inequality-averse, they may reduce their minimum proposal voluntary contributions by beyond the binding minimum. Low-type players may choose a less than maximal minimum proposal if they are (i) sufficiently inequality-averse or (ii) anticipate voluntary contributions exceeding the minimum requirement by high-type agents.
- When low- and high-type players formulate separate binding minimum proposals (*sepcont_q*), high-types implement full contributions $q_H^{\min} = 20$, unless they are sufficiently inequality-averse. Low-type players choose $q_L^{\min} = 0$, unless they are sufficiently inequality-averse. No equilibrium with positive contributions exists in which all players receive equal payoffs.
- When the burden are allocated with the goal of equalizing payoffs (*eqpay*), low-type agents are predicted to choose $Q^{\min} = 44.4$ which requires high-types to contribute $q_H^{\min} = 20$.

3. Experimental design

The experiment was run at the MaXLab laboratory of the University of Magdeburg in Germany with 336 students from various disciplines in November 2011. Each student took part in one of 14 sessions with 24 subjects each that on average lasted 60 min.[6] The experimental design is summarized in Table 1.

We used z-tree software (Fischbacher, 2007) for programming and ORSEE (Greiner, 2004) for recruiting. In each session, we randomly created six groups of four anonymous players with two high-type and two low-type agents (partner matching). No direct communication between participants was allowed. Before starting the experiment on the computer, subjects received a set of experimental instructions which included verbal descriptions, numerical examples and control questions. A session consisted of 12 rounds (including two practice periods) and at the end one non-practice round was randomly chosen to determine individual earnings for each player. The exchange rate between Euro and LabDollar (LD) was 1:2.5 and subjects earned 11 Euros on average (no show-up fee).

[6] Due to a typing error in our z-tree program, we had to remove the results of one group of four players in the first session from our analysis.

Table 1
Summary of experimental design.

Treatment	Stages	No. of subjects (ind. obs.)
VCM	Contribution stage	48 (12)
eqcont_q	Minimum and contribution stage	72 (18)
sepcont_q	Minimum and contribution stage	72 (18)
eqcont_Q	Minimum and contribution stage	68 (17)
eqpay	Minimum and contribution stage	72 (18)

Table 2
Summary statistics for contributions and profits.

Treatment	q_a	q_L	q_H	π_L	π_H	π_a
All periods						
VCM	5.5	3.2	7.7	23.33	27.59	25.46
eqcont_q	6.6	5.8	7.3	22.05	31.10	26.57
sepcont_q	7.2	4.5	9.9	24.13	30.21	27.17
eqcont_Q	7.3	6.3	8.4	22.54	32.37	27.32
eqpay	9.3	3.6	15.1	27.65	31.02	29.34
Periods 6–10						
VCM	3.9	2.0	5.8	22.69	25.13	23.91
eqcont_q	6.4	5.7	7.0	21.91	30.85	26.38
sepcont_q	6.8	3.7	9.9	24.45	29.14	26.80
eqcont_Q	6.8	6.2	7.5	22.06	32.10	26.82
eqpay	9.9	3.4	16.4	28.51	31.32	29.91

Note: q = average contributions: per group (q_a), for low-type (q_L) and for high-type (q_H), π = average profits: for low-type (π_L), for high-type (π_H), and average profits (π_a).

Table 3
Summary statistics for minimum proposals and voluntary contributions.

Treatment	$q_L^{\min_p}$	$q_H^{\min_p}$	$q_H^{\min}$	$q_L^{\min}$	q_a^{delta}	q_L^{delta}	q_H^{delta}
All periods							
eqcont_q	9.8	10.6	4.2	4.2	2.4	1.6	3.1
sepcont_q	5.7	11.3	3.2	8.6	1.3	1.3	1.3
eqcont_Q	41.1	46.1	19.4	19.4	2.5	1.4	3.5
eqpay	63.4	65.6	29.9	29.9	1.9	1.3	2.4
Periods 6–10							
eqcont_q	11.1	11.4	4.9	4.9	1.4	0.8	2.1
sepcont_q	5.2	11.5	4.6	8.6	1.3	1.2	1.3
eqcont_Q	42.8	47.9	20.7	19.4	1.7	1.0	2.3
eqpay	66.4	69.9	33.4	29.9	1.6	0.8	2.3

Note: $q_L^{\min_p}$, average minimum contribution proposals for low-type and $q_H^{\min_p}$ for high-type, $q_L^{\min}$, average binding contribution level for low-type and $q_H^{\min}$ for high-type; $q_a^{delta} = q_a - q_a^{\min}$, average voluntary contribution (q_L^{delta} for low-type, q_H^{delta} for high-type).

We provide instructions for all treatments and screenshots (for *eqpay*) in the Appendix. Apart from *VCM*, each period consists of two stages. In the first stage, players simultaneously suggest a minimum contribution level for (i) individual minimum contribution levels, $q^{\min}$, in *eqcont_q*, (ii) separated individual contribution levels for their own types in *sepcont_q*, or (iii) group minimum contribution levels, $Q^{\min}$, in *eqcont_Q* and *eqpay*. Before making decisions in the second stage, subjects are given information about all suggested minimum proposals, and the individual minimum contribution is derived according to the specific burden sharing rule and displayed to the subject. Players then simultaneously decide upon their contributions $q_i \geq q_i^{\min}$. At the end of the period, all players' contributions (in tokens) and period's payoffs (in Labdollars LD) are revealed to the subjects.

4. Experimental results

Our experimental design enables us to investigate which mechanisms perform best when heterogeneous individuals have the option to contribute to a public good. We craft our results both by pooling the data across all ten periods and by reporting the results in the last five periods. We later explore the effects of time on contribution schedules in more detail.

Table 2 provides mean contribution levels for each of our treatments and Fig. 1 provides a graphical depiction of the data. Averaged over all periods, contributions are lowest in *VCM* (5.5 tokens) and highest in the equal-payoff treatment *eqpay* (9.3). These differences are even more pronounced when concentrating on the last five periods (*VCM* 3.9, *eqpay* 9.9). While a comparison of contributions is indicative of the obtained efficiency, we first focus on the payoff comparisons across

Table 4
Random-effects regression of profit levels.

Variables	(1) Profit Periods 1–10		(2) Profit Periods 1–10		(3) Profit Periods 1–10		(4) Profit Periods 1–10		(5) Profit Periods 6–10		(6) Profit Periods 6–10	
	Coeff. (st. error)	*p*-Value	Coeff. (st. error)	*p*-Value	Coeff. (st. error)	*p*-Value	Coeff. (st. error)	*p*-Value	Coeff. (st. error)	*p*-Value	Coeff. (st. error)	*p*-Value
eqcont_q	1.112 (1.166)	0.340	−0.246 (1.293)	0.849	−2.642*** (1.022)	0.010	−1.787** (0.874)	0.041	2.469* (1.313)	0.060	−0.781 (0.685)	0.254
sepcont_q	1.709 (1.119)	0.127	0.529 (1.355)	0.696	−0.378 (1.026)	0.713	−0.157 (0.911)	0.863	2.889*** (1.099)	0.009	1.761* (0.931)	0.059
eqcont_Q	1.991* (1.098)	0.070	0.811 (1.461)	0.579	−1.976* (1.155)	0.087	−0.962 (0.794)	0.226	3.171** (1.253)	0.011	−0.630 (0.710)	0.375
eqpay	3.876*** (0.962)	0.000	1.747 (1.225)	0.154	2.185** (0.976)	0.025	2.813*** (0.908)	0.002	6.005*** (0.951)	0.000	5.815*** (0.842)	0.000
per6_10_VCM			−3.104*** (0.633)	0.000	−3.104*** (0.634)	0.000	−1.283*** (0.423)	0.002				
per6_10_eqcont_q			−0.389 (0.972)	0.689	−0.389 (0.973)	0.689	−0.278 (0.376)	0.460				
per6_10_sepcont_q			−0.744 (0.817)	0.362	−0.744 (0.818)	0.363	0.634 (0.662)	0.338				
per6_10_eqcont_Q			−0.744 (1.475)	0.614	−0.744 (1.476)	0.614	−0.952* (0.494)	0.054				
per6_10_eqpay			1.154 (0.837)	0.168	1.154 (0.838)	0.169	1.719** (0.675)	0.011				
high_VCM					4.257*** (0.982)	0.000	6.078*** (1.345)	0.000			2.437** (1.040)	0.019
high_eqcont_q					9.049*** (1.407)	0.000	9.160*** (1.240)	0.000			8.938*** (1.937)	0.000
high_sepcont_q					6.071*** (1.616)	0.000	7.450*** (1.705)	0.000			4.692*** (1.619)	0.004
high_eqcont_Q					9.831*** (1.381)	0.000	9.624*** (1.773)	0.000			10.04*** (1.790)	0.000
high_eqpay					3.381*** (1.268)	0.008	3.945*** (1.433)	0.006			2.816** (1.325)	0.034
high_per6_10_VCM							−3.642*** (1.386)	0.009				
high_per6_10_eqcont_q							−0.222 (1.630)	0.892				
high_per6_10_sepcont_q							−2.758*** (0.772)	0.000				
high_per6_10_eqcont_Q							0.415 (2.250)	0.854				
high_per6_10_eqpay							−1.129 (1.085)	0.298				
Constant	25.46*** (0.756)	0.000	27.01*** (0.957)	0.000	24.88*** (0.776)	0.000	23.97*** (0.677)	0.000	23.91*** (0.655)	0.000	22.69*** (0.621)	0.000
Observations	3320		3320		3320		3320		1660	1660		
R-sq	0.03		0.03		0.25		0.25		0.05	0.24		

Definition of variables	
q_i	Subject's contribution
Profit	Subject's payoff
eqcont_q	=1 if subject played treatment *eqcont_q*, 0 otherwise
sepcont_q	=1 if subject played treatment *sepcont_q*, 0 otherwise
eqcont_Q	=1 if subject played treatment *eqcont_Q*, 0 otherwise
min_I_Q_eq	=1 if subject played treatment *eqcont_q-eq*, 0 otherwise
*per6_10_*treatment**	=1 for the last five periods and subject played *treatment*, 0 otherwise
*high_*treatment**	=1 if subject played *treatment* and is a high-type, 0 otherwise
*high_per6_10_*treatment**	=1 for the last five periods and subject is a high-type and subject played *treatment*, 0 otherwise

Note: We consider individual level random effects, i.e. one observation for one individual corresponds to the panel variable and the period sets the time variable: 332 individual observations × 10 periods (last two columns: 5 periods) = 3320 (1660) total observations, robust standard errors in parentheses, adjusted for group clusters. * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

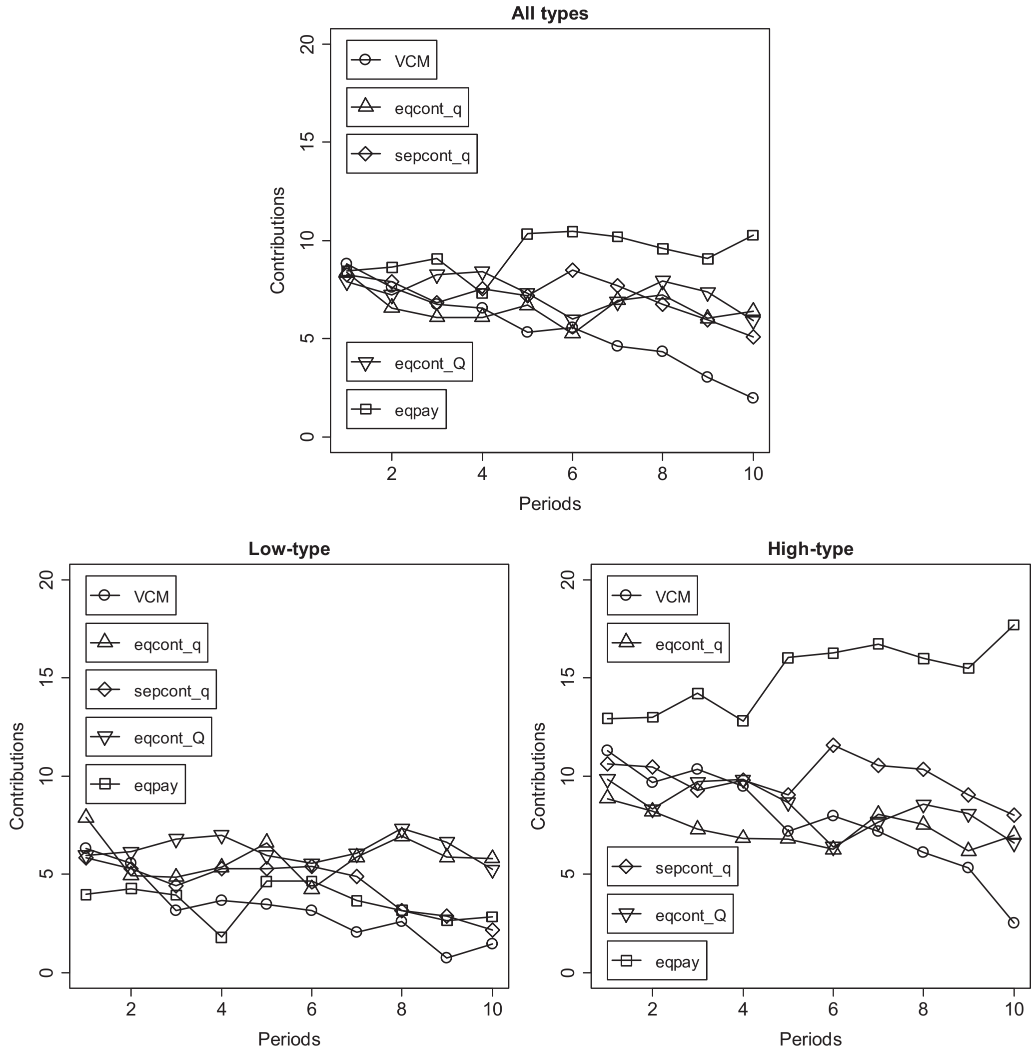

Fig. 1. Mean contributions over time.

treatments (see also Fig. 2). Our statistical analysis is based on a series of random-effects regression models (Tables 3–5)[7] and non-parametric Mann–Whitney *U* (MW-*U*) tests.[8] Throughout the paper our discussion is primarily based on the regression results. In order to avoid repetitions, we refer to MW-*U* tests only in cases where differences between the two statistical methods appear. The results from those are summarized in the supplementary material.

Focusing on the last five periods, average profit over all players is minimal in *VCM* (23.91 LD) and reaches its maximum in *eqpay* (29.91 LD). Hereby, average payoffs are significantly larger under all rules than under *VCM* ($p < 0.1$ for *eqcont_q*, $p < 0.05$ for *eqcont_Q* and $p < 0.01$ for all other treatments, Table 4, column 5).[9] The average payoffs are largest in *eqpay* ($p < 0.05$ for *eqcont_Q*, $p < 0.01$ for all other treatments, Table 5, column 5). Benefits of rule-based provision of public goods relative to

[7] This estimation procedure enables us to allow for unobserved subject-specific differences. We use a random-effects Feasible Generalized Least Square estimator (RE FGLS) for determining differences in individual payoffs. We consider individual level random effects, i.e. one observation of one individual corresponds to the panel variable and the period sets the time variable because we do not expect individual observations to be independent over periods. We do expect groups do be independent of each other because of the partner matching and the random assignment of subjects to groups at the beginning of the experiment. Hence, we include 3320 observations (332 individuals × 10 periods) if the regression analysis if all periods are considered and 1660 observations (332 individuals × 5 periods) if the analysis refers to the second half of the experiment (columns 5 and 6, Table 4). Moreover, the discussion of the regression results throughout the paper is based on standard errors clustered at group levels. Exact *p*-values are included in the regression tables.

[8] In this section, we refer to exact two-sided MW-*U* tests with the average contribution by one group or subgroup (high-type or low-type) averaged over all periods or over the last five periods as the unit of observation.

[9] Significance in MW-*U* tests is not obtained for *eqcont_q* and *eqcont_Q*.

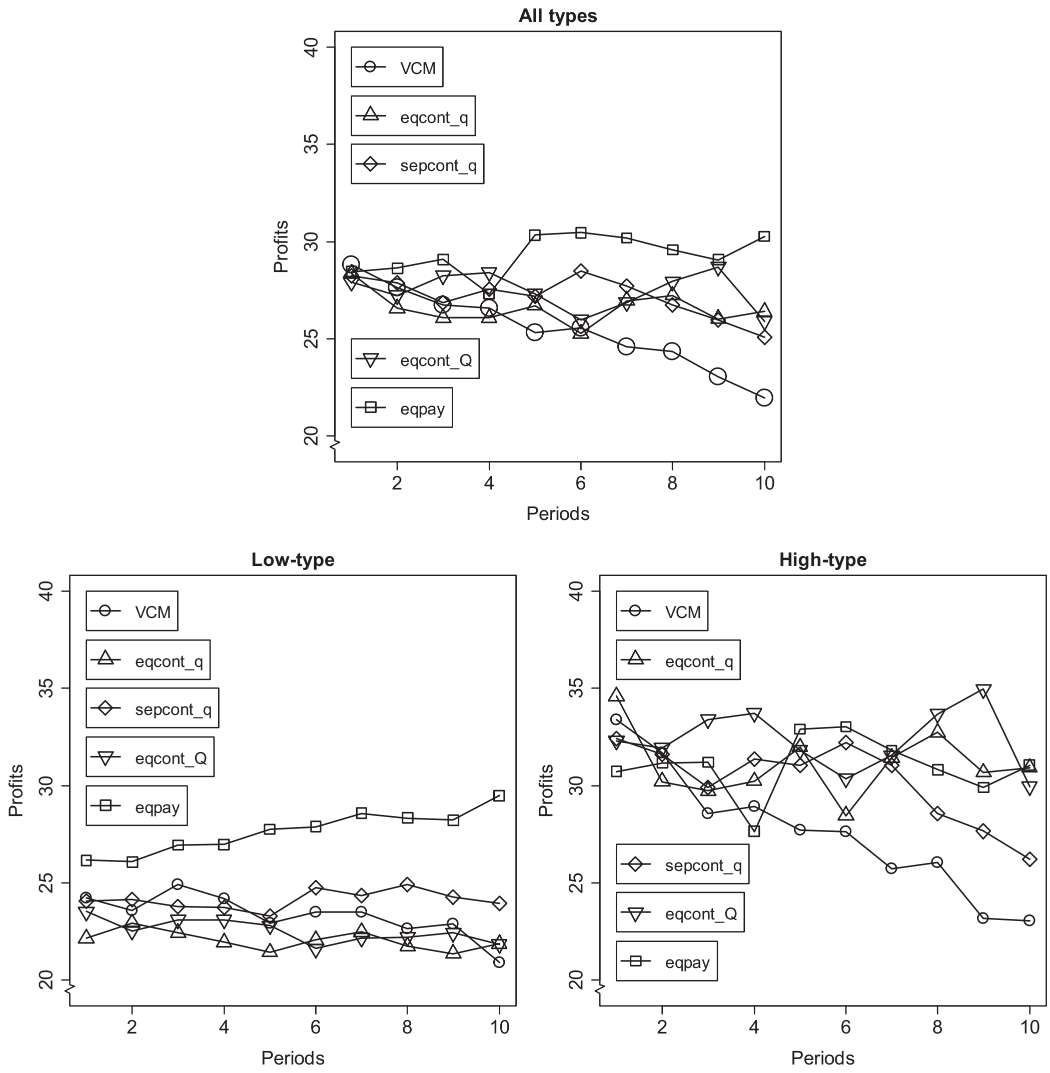

Fig. 2. Mean profits over time.

VCM particularly occur over time: average profits decline in *VCM* ($p < 0.01$), while the trends are less negative in all other treatments (Table 4, column 2 and Table 5) and even positive in *eqpay* ($p < 0.01$ based on a Jonckheere–Terpstra test, see Table 10).

We therefore establish the following result on the benefits of rule-based contribution schemes:

Result 1. *Rule-based contribution schemes lead to larger payoffs than VCM in the final rounds.*

While Result 1 was expected under our theoretical predictions, it nicely adds to findings by Orzen (2008) and Dannenberg et al. (2014) who show the benefits from minimum-rules for homogeneous agents. We show that such minimum-contribution rules may also generate efficiency gains when agents differ significantly in their benefits from the public good. This even holds for rules that require equal contributions from all players.

The rules differ significantly in the distribution of their benefits across players. High-type players receive higher payoffs than low-types in all treatments including *VCM* ($p < 0.05$ for *VCM* and *eqpay*, $p < 0.01$ for all other treatments, Table 4, column 6). Relative to *VCM*, they benefit both in treatments with equal minimum contribution levels ($p < 0.05$ for *eqcont_q*, $p < 0.01$ for *eqcont_Q*, Table 5) and if burden are allocated differently across players in contrast to *VCM* ($p < 0.05$ for *sepcont_q*, $p < 0.01$ for *eqpay*, Table 5). Low-types benefit relative to *VCM* only if the implemented rule explicitly differentiates the burden ($p < 0.1$ for *sepcont_q* and $p < 0.01$ for *eqpay*, Table 4, column 6). In *eqcont_q* and *eqcont_Q*, low-types tend lose relative to *VCM* such that low-type players' profits in *sepcont_q* and *eqpay* is significantly larger than in *eqcont_q* and *eqcont_Q* ($p < 0.01$, Table 5). In fact, low-type agents benefit most in *eqpay* ($p < 0.01$ relative to all other treatments, Table 5). It should be noted that the

Table 5
Postestimation Wald tests on selected explanatory variables after random-effects regression of profit levels.

Column (1)	Periods 1–10			
Coefficient	*VCM*	*eqcont_q*	*sepcont_q*	*eqcont_Q*
eqcont_q	$>$			
sepcont_q	$>$	$>$		
eqcont_Q	$>^{*}$	$>$	$>$	
eqpay	$>^{***}$	$>^{***}$	$>^{**}$	$>^{*}$
Column (2)	Periods 1–10			
Coefficient	*per6_10_VCM*	*per6_10_eqcont_q*	*per6_10_sepcont_q*	*per6_10_eqcont_Q*
per6_10_eqcont_q	$>^{**}$			
per6_10_sepcont_q	$>^{**}$	$<$		
per6_10_eqcont_Q	$>$	$<$	$<$	
per6_10_ eqpay	$>^{***}$	$>$	$>$	$>$
Column (5)	Periods 6–10			
Coefficient	*VCM*	*eqcont_q*	*sepcont_q*	*eqcont_Q*
eqcont_q	$>^{*}$			
sepcont_q	$>^{***}$	$>$		
eqcont_Q	$>^{**}$	$>$	$<$	
eqpay	$>^{***}$	$>^{***}$	$>^{***}$	$>^{**}$
Column (6)	Periods 6–10			
Coefficient	*VCM*	*eqcont_q*	*sepcont_q*	*eqcont_Q*
Low-type players				
eqcont_q	$<$			
sepcont_q	$>^{*}$	$>^{***}$		
eqcont_Q	$<$	$>$	$<^{***}$	
eqpay	$>^{***}$	$>^{***}$	$>^{***}$	$>^{***}$
High-type players				
eqcont_q	$>^{**}$			
sepcont_q	$>^{**}$	$>$		
eqcont_Q	$>^{***}$	$>$	$>$	
eqpay	$>^{***}$	$>$	$>$	$<$

Note: We compare rows with columns. $^{***}p<0.01$, $^{**}p<0.05$, $^{*}p<0.1$, We test whether the difference of two estimated coefficients is significantly different from zero, e.g. we test whether $b[eqcont\_q] = b[sepcont\_q]$. In order to compare effects for high-type players after the model estimated in column 6 we combine the corresponding estimated coefficients, e.g. we test whether $b[eqcont\_q] + b[high\_eqcont\_q] = b[sepcont\_q] + b[high\_sepcont\_q]$.

benefits from *eqpay* for low-type agents get more pronounced over time based on a Jonckheere–Terpstra test ($p < 0.01$, see Table 10).

The profit gains for low-type agents from differentiating the burden thereby significantly hurt the high-type agents when comparing *eqcont_q* (32.10 LD) with *sepcont_q* (29.14 LD). Importantly, however, also high-type agents benefit from the equal-payoff rule *eqpay* (31.32 LD) ($p < 0.01$ for *VCM*, coefficients are not significant for other treatments, Table 5). That is, the equal-payoff rule maximizes the payoffs to both low- and high-type agents.

We therefore obtain the following result:

Result 2. *The equal-payoff rule payoff-dominates all other burden sharing rules, including the VCM, in the final rounds.*

While Result 1 has focused on the benefits of all rules relative to *VCM*, Result 2 may be particularly surprising as a theory based on payoff-maximizing preferences would predict all rules leading to equilibria corresponding to different points (B, C, and D in Fig. 3) along the efficient boundary, while point A corresponds to zero contributions as predicted for *VCM*. However, based on our model of inequality aversion, we had predicted that the equal-payoff rule may outperform other rules as inequality-averse low-type agents may suggest smaller contribution levels in the uniform rules (*eqcont_q* and *eqcont_Q*) in order to reduce the payoff-inequality.

To better understand the causes for Result 2, Fig. 3 plots average profits for high- and low-type players for each group in the last five periods for the different treatments. It can be seen that almost no group reaches the payoff-maximizing provision level, even though significant profit gains relative to *VCM* predictions are realized. For the payoff-equality rule in *eqpay* (along AD) average efficiency gains were largest. In this treatment, many groups managed to come close to the efficiency frontier.

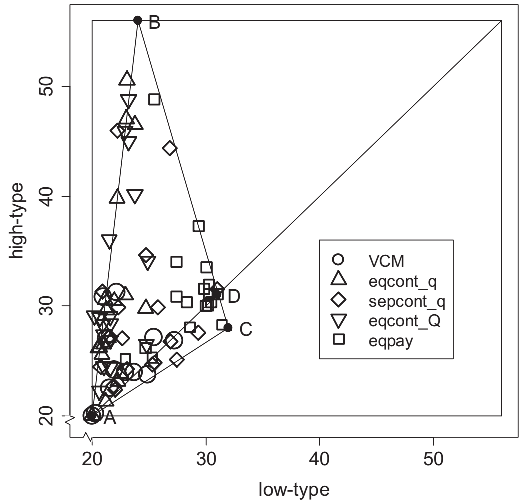

Fig. 3. Profits per group (average over periods 6–10). *Note*: the equilibrium predictions for payoff-maximizing players are given by points A for *VCM*, B for *eqcont_q* and *eqcont_Q*, C for *sepcont_q*, and D for *eqpay*.

Table 6
FGLS random-effects regression of contributions to the public good.

Variables	(1) q_i Periods 1–10		(2) q_i Periods 1–10		(3) q_i Periods 6–10	
	Coeff. (st. error)	*p*-Value	Coeff. (st. error)	*p*-Value	Coeff. (st. error)	*p*-Value
eqcont_q	1.260 (1.112)	0.257	1.492 (1.120)	0.183	3.744*** (1.331)	0.005
sepcont_q	0.0687 (1.338)	0.959	0.792 (1.301)	0.543	1.706 (1.108)	0.124
eqcont_Q	2.002 (1.350)	0.138	1.935 (1.369)	0.158	4.165*** (1.249)	0.001
min_I_Q_eq	−1.792 (1.199)	0.135	−0.717 (1.164)	0.538	1.391 (0.963)	0.149
per6_10_VCM	−3.104*** (0.634)	0.000	−2.442*** (0.798)	0.002		
per6_10_eqcont_q	−0.389 (0.973)	0.689	−0.189 (0.998)	0.850		
per6_10_sepcont_q	−0.744 (0.818)	0.363	−1.528*** (0.502)	0.002		
per6_10_eqcont_Q	−1.009 (1.480)	0.495	−0.212 (1.397)	0.880		
per6_10_eqpay	1.154 (0.838)	0.169	−0.334 (0.656)	0.611		
high_VCM	4.479*** (1.016)	0.000	5.142*** (1.114)	0.000	3.817*** (1.084)	0.000
high_eqcont_q	1.467** (0.631)	0.020	1.667* (0.895)	0.063	1.267*** (0.430)	0.003
high_sepcont_q	5.400*** (1.049)	0.000	4.617*** (1.087)	0.000	6.183*** (1.251)	0.000
high_eqcont_Q	2.097*** (0.493)	0.000	2.894*** (0.629)	0.000	1.300** (0.540)	0.016
high_eqpay	11.56*** (0.913)	0.000	10.07*** (1.100)	0.000	13.04*** (1.040)	0.000
high_per6_10_VCM			−1.325 (0.836)	0.113		
high_per6_10_eqcont_q			−0.400 (0.615)	0.515		
high_per6_10_sepcont_q			1.567 (1.045)	0.134		
high_per6_10_eqcont_Q			−1.594** (0.635)	0.012		
high_per6_10_eqpay			2.976*** (1.115)	0.008		
Constant	4.773*** (0.787)	0.000	4.442*** (0.820)	0.000	2*** (0.592)	0.001
Observations	3320		3320		1660	
R-sq	0.26		0.26		0.32	

Note: We consider individual level random effects, i.e. one observation for one individual corresponds to the panel variable and the period sets the time variable: 332 individual observations × 10 periods (last two columns: 5 periods) = 3320 (1660) total observations. Robust standard errors in parentheses, adjusted for group clusters. * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

The payoff differences between treatments naturally correspond to different contribution levels that can be observed in our random-effects regression models in Table 6.[10] For average contributions to the public good across all players in the last

[10] We follow our estimation strategy which we applied for determining differences in individual payoffs and use a random-effects Feasible Generalized Least Square estimator (RE FGLS) for analyzing individual contribution behavior. Further RE FGLS specifications beyond those reported in Table 6 are given in the supplementary material. In addition, for robustness check, we further apply a Tobit estimator (RE Tobit). The latter estimator controls for the fact that the dependent variable (individual contributions to the public good in each period) is both left- and right-censored with a lower limit of 0 (20.12% of all contribution decisions) and an upper limit of 20 (9.67% of all contribution decisions). Specification tests suggest that the results of the Tobit estimator are not sensitive to the number of quadrature points used in the estimation process. We do not report regression results from RE Tobit model in the paper since the main results do not differ between the two estimation models.

Table 7
Postestimation Wald tests on selected explanatory variables after random-effects regression of contribution levels.

Column (3)	Periods 6–10			
Coefficient	*VCM*	*eqcont_q*	*sepcont_q*	*eqcont_Q*
Low-type players				
eqcont_q	>*			
sepcont_q	>***	<		
eqcont_Q	>**	>	>*	
eqpay				
High-type players				
eqcont_q	>			
sepcont_q	>**	>*		
eqcont_Q	>	>	<	
eqpay	>***	>***	>***	>***

Note: We compare rows with columns. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$, We test whether the difference of two estimated coefficients is significantly different from zero, e.g. we test whether $b[eqcont\_q] = b[sepcont\_q]$. In order to compare effects for high-type players after the model estimated in column 6 we combine the corresponding estimated coefficients, e.g. we test whether $b[eqcont\_q] + b[high\_eqcont\_q] = b[sepcont\_q] + b[high\_sepcont\_q]$.

Table 8
Random-effects regression of changes in individual minimum proposals $q_i^{\min_p}(t+1) - q_i^{\min_p}(t)$.

Variables	(1) $q_i^{\min_p}(t+1) - q_i^{\min_p}(t)$	
	Coeff. (st. error)	p-Value
Pivotal (in t)	3.272*** (0.306)	0.000
High	0.724*** (0.155)	0.000
Q (in t)	−0.0477*** (0.00705)	0.000
sepcont_q	−1.171*** (0.264)	0.000
eqcont_q	0.172 (0.257)	0.502
eqpay	0.392 (0.269)	0.145
Constant	0.125 (0.265)	0.638
Observations	2556	
R-sq	0.10	

Note: We consider individual level random effects, i.e. one observation for one individual corresponds to the panel variable and the period sets the time variable: 284 individual observations × 9 periods = 2556 (total observations). Robust standard errors in parentheses, adjusted for group clusters. Definition of variables: $q_i^{\min_p}(t+1) - q_i^{\min_p}(t)$ = difference in subject's minimum proposal between periods $t+1$ and t, pivotal (in t) = 1 if subject set the minimum binding contribution level in period t, high = 1 if subject is a high-type player, Q (in t) = group contribution level in period t. $^{*}p < 0.1$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

five periods, in all treatments the differences are identical to the already discussed payoff differences. That is, contributions are higher than in *VCM* with the effect being strongest in *eqpay*. We observe a positive time trend for *eqpay* over all periods ($p < 0.01$, see Table 11), but rather declining average contributions for all other treatments. The temporal trends are again illustrated in Fig. 1 which also shows how both types contribute to these differences.

It is obvious that the rules that explicitly differentiate burdens across types lead to significant differences in contributions by agents. For low-type players, we observe that contributions decline over time in *VCM* and *sepcont_q*, but are rather stable in the other treatments (Table 11). Due to the explicit differentiation of burdens, the increases in average absolute contributions in *eqpay* and *sepcont_q* relative to *VCM* are thereby largely driven by increased contributions by high-type players (Table 7): contributions by high-type players in *sepcont_q* are stable for high-type players and even increasing in *eqpay* ($p < 0.01$, see Table 11) which leads to significantly larger contributions than any other treatment across the last 5 periods ($p < 0.01$, Table 7). This increase in contributions by high-type players thereby drives the dominance of the equal-payoff rule as observed in Result 2.

We can formulate the following result:

Result 3. *Average contributions increase over time when the rule implements equal payoffs, but show a downward trend in all other treatments, particularly in VCM. For low-type players, there is no downward trend when equal minimum contributions are enforced such that these treatments lead to higher contributions by low-type players in the last periods than the other treatments. For high-type players, contributions are largest under the equal-payoff rule and even increase over time.*

Result 3 complements the previous two results: the dominance of *eqpay* appears to be primarily driven by increased contributions by high-type players themselves. They contribute 16.4 tokens on average in the last five periods in *eqpay*, while their contributions are significantly smaller in all other treatments ($p < 0.01$, Table 7). Conversely, low-type agents contribute less in this treatment (3.4 tokens) than under any other non-differentiating rule-based scheme (5.7 in *eqcont_q*, $p < 0.05$, 6.2 in *eqcont_Q*, $p < 0.1$, Table 7). Interestingly, low-type agents' contributions are not significantly different in *sepcont_q* (3.7) than under the equal-payoff treatment.

Table 9
Random-effects regression of differences in q_i^{delta}.

Variables	(1) $q_i^{delta}a$		(2) q_i^{delta}	
	Coeff. (st. error)	p-Value	Coeff. (st. error)	p-Value
qmin_p	0.0477** (0.0196)	0.015	0.00363 (0.0175)	0.835
high_eqcont_q	1.564** (0.679)	0.021		
high_sepcont_q	−0.294 (0.331)	0.375		
high_eqcont_q	1.739** (0.714)	0.015		
high_eqpay	0.495 (0.831)	0.551		
pivotal_eqcont_q			−1.581*** (0.343)	0.000
pivotal_sepcont_q			−1.334*** (0.267)	0.000
pivotal_eqcont_q			−1.784*** (0.309)	0.000
pivotal_eqpay			−0.984*** (0.248)	0.000
Constant	1.032*** (0.178)	0.000	2.495*** (0.277)	0.000
Observations	2840		2840	
R-sq	0.05		0.06	

Note: We consider individual level random effects, i.e. one observation for one individual corresponds to the panel variable and the period sets the time variable: 284 individual observations × 10 periods = 2840 (total observations), robust standard errors in parentheses, adjusted for group clusters, definition of variables: q_i^{delta} = voluntary contribution above minimum requirement, *qmin_p* = subject's suggested minimum contribution level, *pivotal_*treatment** = 1 if subject played *treatment*and set the minimum binding contribution level in the corresponding period. * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

Table 10
Time trends in profits over time.

Treatment	*VCM*	*eqcont_q*	*sepcont_q*	*eqcont_q*	*eqpay*
All players	▼***	▼*	▼**	▼*	▲***
Low-type	▼***	▼*		▼**	▲***
High-type	▼***	▼*	▼***		

Note: Average profits per (sub-)group in each of the ten periods of the game serve as one observation. Statistical results for time trends are based on a nonparametric Jonckheere–Terpstra for ordered differences of a response variable among classes, the null hypothesis states that the distribution of the frequency of a given profit level does not differ among rounds. ▼ = decreasing profits over time, ▲ = increasing profits over time. * $p < 0.1$, ** $p < 0.05$, and *** $p < 0.01$.

It should be noted, however, that agents often contribute more than the required minimum. We report the average differences between binding minimum and actual contributions (q_{delta}) in Table 3. Players go beyond their minimum requirements mainly in treatments where equal minimum contribution levels are enforced (q_{delta} = 2.4 in *eqcont_q* and 2.5 in *eqcont_Q* over all periods). For these schemes, additional voluntary contributions to the public good mainly stem from high-type players (3.1 in *eqcont_q* and 3.5 in *eqcont_Q*). In terms of our theory, this tendency is consistent with (i) low-type agents being inequality-averse and making smaller minimum proposals, while (ii) inequality-averse high-type agents contribute beyond the minimum in order to decrease inequality. Consistent with this reasoning, we do not find any difference in voluntary contributions beyond the respective minimum requirement for high- and low-type players when separated minimum levels are implemented (both 1.3 in *sepcont_q*) and also a smaller difference in *eqpay* (2.4 vs. 1.3). Our regression results in Table 9 confirm this finding. High-type players have larger voluntary contributions under treatments that specify equal minimum contribution levels ($p < 0.05$, Table 9, column 1). For all treatments, we find that pivotal players, i.e. those players whose minimum proposal are implemented at the group level, have smaller voluntary contributions beyond the minimum than other players ($p < 0.01$, Table 9, column 2). That is, players who made a minimum proposal which exceeded the implemented minimum have larger voluntary contributions, i.e. they tend to be impacted by their initial proposal.

We therefore now study the choice of minimum proposals in more detail. When equal minimum contributions are implemented (in *eqcont_q* and *eqcont_Q*), payoff-maximizing players should propose full contribution ($q^{\min} = 20$ in *eqcont_q*, $Q^{\min} = 80$ in *eqcont_Q*) as shown in Section 2. In our experiment, both types of players on average propose about 50% of full contribution levels and agree upon an average binding minimum contribution level of 4.2 tokens in *eqcont_q* and 19.4 tokens in *eqcont_Q* respectively. That is, in an equal contribution scheme less than 25% of the payoff-maximizing contribution level is achieved. In the vast majority of the cases (78% in *eqcont_q* and 87% in *eqcont_Q*) only one single (predominantly low-type) player sets the binding minimum contribution level. One possible explanation for these rather low cooperation gains might indeed be inequality concerns that hamper the coordination towards higher minimum contribution levels.

When separate minimum requirements are implemented for high- and low-type players in *sepcont_q*, low-type players implement a higher binding minimum (3.2 tokens) than predicted under payoff-maximization (0 tokens). High-type players, however, on average agree upon less than half of the predicted (full) contribution level. In fact, only 3 out of 18 groups of high-type players in *sepcont_q* achieve a binding minimum proposal of at least 18 in period 10. Seven groups of high-type players do not achieve any cooperation, i.e. stay at a zero level in period 10. In 84% of the cases, a single high-type player is pivotal and prevents a larger minimum. As laid out in Section 2, such behavior is consistent with inequality aversion as higher commitment levels would generate larger net benefit to low-type agents.

Table 11
Time trends in contributions over time.

Treatment	*VCM*	*eqcont_q*	*sepcont_q*	*eqcont_q*	*eqpay*
All players	▼***	▼*	▼**	▼**	▲***
Low-type	▼***		▼***		
High-type	▼***			▼**	▲***

Note: Average contributions per (sub-)group in each of the ten periods of the game serve as one observation. Jonckheere–Terpstra for ordered differences of a response variable among classes, the null hypothesis states that the distribution of the frequency of a given contribution level does not differ among rounds. ▼ = decreasing profits over time, ▲ = increasing profits over time. *$p < 0.1$, **$p < 0.05$, and ***$p < 0.01$.

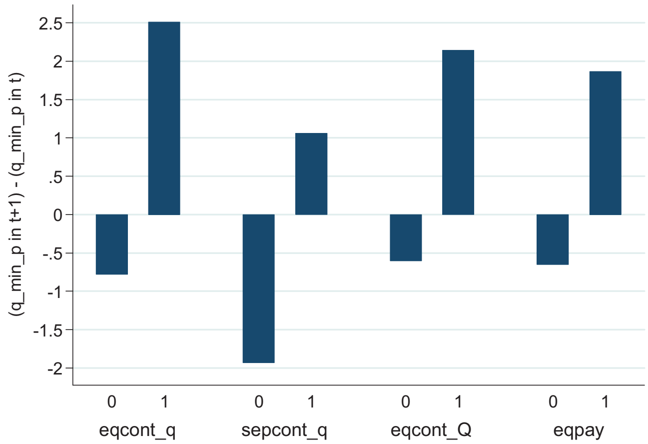

Fig. 4. Differences in minimum proposals depending on the pivotal status. *Note*: 0 = non-pivotal in *t*, 1 = pivotal in *t*.

Table 12
Time trends in minimum contribution proposals over time.

Treatment	*eqcont_q*	*sepcont_q*	*eqcont_q*	*eqpay*
All players	▲***		▲***	▲***
Low-type	▲***	▼*	▲*	▲**
High-type	▲**		▲***	▲***

Note: Average minimum contribution proposals per (sub-)group in each of the ten periods of the game serve as one observation. Jonckheere–Terpstra for ordered differences of a response variable among classes, the null hypothesis states that the distribution of the frequency of a given minimum contribution proposal level does not differ among rounds. ▼ = decreasing profits over time, ▲ = increasing profits over time. *$p < 0.1$, **$p < 0.05$, and ***$p < 0.01$.

Table 13
Time trends in binding minimum contribution levels over time.

Treatment	*eqcont_q*	*sepcont_q*	*eqcont_q*	*eqpay*
All players	▲**			▲***
Low-type		▼***		
High-type				

Note: Binding minimum contribution proposals per (sub-)group in each of the ten periods of the game serve as one observation. Jonckheere–Terpstra for ordered differences of a response variable among classes, the null hypothesis states that the distribution of the frequency of a given binding minimum contribution level does not differ among rounds. ▼ = decreasing profits over time, ▲ = increasing profits over time. *$p < 0.1$, **$p < 0.05$, and ***$p < 0.01$.

In *eqpay*, players on average implement a minimum contribution level of 29.9 tokens, representing about 68% of predicted payoff-efficiency gains. Here, in 83% of the cases a single player, mostly low-type, is pivotal in determining the binding minimum. 14 out of 18 groups in *eqpay* achieve a total provision level of the public good that requires high-type players to contribute at least 18 in period 10. Considering only the minimum proposals by high-type players, all 18 groups of two would suggest to take on at least 18 tokens as obligation. 16 pairs of high-type players in *eqpay* suggest provision levels in period 10 that would require them to contribute all 20 tokens.

The fact that usually a single player is pivotal and determines the minimum triggers the question if such a player will update the minimum proposal in the next period in order to increase the group's binding minimum. Indeed, Fig. 4 illustrates the changes in minimum proposals depending on the pivotal status in time period t: in all treatments, pivotal players on average increase their minimum proposals in the next period, while non-pivotal players tend to reduce their suggestion. This finding is supported by corresponding regression results in Table 8. The changes in the individual suggestion lead to substantial treatment differences for the implemented binding minimum level (see Tables 12 and 13).[11] In *eqcont_Q* we do observe neither a positive nor a negative trend since low-type players who are pivotal in 87% of the cases fail to increase their proposals, while a positive trend exists for *eqcont_q*. When players formulate separate minimum proposals in *sepcont_q*, the suggested and binding minimum contribution by low-types even decreases over time, while high-types are stable. That is, even though high-types would benefit in terms of payoff from increasing their own binding minimum, they fail to do so. For the equal-payoff rule, we find that the suggestions by both types of players as well as the binding minimum level are increasing over time. Summarizing these findings, we therefore formulate the following result:

Result 4. *A burden sharing scheme which equalizes the payoffs between all players allows high-type players to coordinate over time more effectively than a scheme under which players of the different types separately choose their binding minimum contribution levels.*

We consider Result 4 as being rather surprising: it is obvious that payoff-maximizing low-type agents under the equal-payoff scheme will suggest high provision levels up to $Q^{min} = 44$ which would require almost full contribution of high-type subjects, but relatively little from low-type players. Anticipating low-types' payoff maximization behavior, high-type agents' best answer is to suggest a minimum which is equal or higher than $Q^{min} = 44$. Effectively, this scheme therefore should have similar effects as the *sepcont_q* treatment where the two high-type players choose their binding contribution level only among themselves. However, we observe significantly less efficient choices in *sepcont_q* which leads to the dominance of the equal-payoff rule.

The missing cooperation among high-type players in *sepcont_q* stands in conflict with findings by Orzen (2008) and Dannenberg et al. (2014) who show that homogenous groups achieve large cooperation levels under the lowest common denominator scheme. Our results therefore suggest that coordination is hampered when other, different-type players, are present. This difference in the decisions by high-type players in *sepcont_q* and *eqpay* is particularly surprising as the average contributions of low-type players do not differ between the two treatments. The difference can therefore not be explained by inequality-aversion: as shown in Section 2, the predictions in *eqpay* do not depend on the level of inequality-aversion. In *sepcont_q*, high-type players who – given the contribution decisions – earn more than the low-type players – also should increase their minimum proposal, independent of whether or not they are inequality-averse. As high-type players fail to do so, we can therefore only speculate about the reasons for this dominance of the equal-payoff treatment: on the one hand, *eqpay* may have intuitively appealing properties for inequality-averse agents as it automatically equalizes payoffs. On the other hand, efficiency may be improved in *eqpay* since *all* players' suggested minimum levels for the aggregate provision level are treated identically. Differently in *sepcont_q*, each player type makes proposals that are treated separately. As a result, high-type players may be influenced by explicitly observing small minimum proposals from low-type players, while not recognizing that decoupling from those by coordinating only among themselves increases payoffs for the two high-type players.

5. Conclusions

Forming institutions to secure the provision of global public goods is a complicated endeavor. In general, the success of a decentralized institution to provide a public good depends on two interlinked challenges: on the one hand, the institutional arrangements need to overcome free rider incentives. On the other hand, as soon as subjects are heterogeneous, any given institution has to cope with equity issues or equivalently the burden sharing of the total costs.

In this paper, we tested different institutions with respect to their ability to succeed along these two dimensions. In particular, we investigated how burden sharing rules may impact the provision level of a public good that all agents voluntarily accept. We focused on rule-based contribution mechanisms that are based on the principle of the smallest common denominator: all agents can suggest a minimum provision level of the public good that is allocated across agents according to some predetermined rule. The minimum of all proposals, i.e. the lowest common denominator, then creates a threshold for the own contribution.

Our results indicate that rule-based contribution schemes significantly increase payoff levels relative to the voluntary contribution mechanism. Interestingly, the performance of the single ("one for all") smallest common denominator rule in our experiment is rather weak. While recent experiments have shown that this rule is quite successful under homogeneous players, we get a different picture under heterogeneity. Importantly, the equal-payoff rule where the minimum threshold is chosen in a way that payoffs are equalized payoff-dominates all other rules and therefore should be preferred by all agents. This holds in particular relative to the scheme where high- and low-type players separately can determine their minimum contribution: here, low-type agents end up contributing at the same rate as in the equal-payoff treatment while high-type agents fail to even come close to their predicted payoff-maximizing contribution level.

Returning to our introductory example of international climate policy, our results may shed some light on the recent discussion in climate policy. In order to accelerate negotiations for a post-Kyoto agreement sub-agreements between rather homogenous countries are suggested. In our environment, these sub-agreements fail to produce efficiency. Instead, subjects with high marginal benefit contribute at a significantly higher level only when they know that the redistribution is explicitly

[11] We illustrate typical development of minimum proposals for the four treatments in the supplementary material.

enforced by the mechanisms. As a caveat, we note that our experimental design automatically enforced the implemented binding minimum while in the field sovereign players may deviate from initially accepted rules. The concept of minimum contribution rules is, however, more generally applicable to situations where people face social dilemma situations as in the provision of local public goods.

Overall, our results underline the importance of equity in the provision of public goods and indicate that rules with congruence between the distribution of costs and the benefits (see Dayton-Johnson, 2000a,b) may indeed lead to largest cooperation levels. The investigation of the performance of different institutions for other aspects of heterogeneity such as heterogeneous costs, endowments or ways to generate the endowment ("house money effects") remains a fruitful area for further research.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jebo.2014.04.024.

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