Public–good experiments with large groups

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Abstract

Many of real–world public–goods are characterized by a marginal per capita return (MPCR) close to zero and have to be provided by large groups. Up until now, there is almost no evidence on how large groups facing a low MPCR behave in controlled public–good laboratory experiments involving financial incentives. Connecting four experimental laboratories located in four different German universities via Internet, we are able to run such experiments. In addition to the group size (60 and 100 subjects), we vary the MPCR which is as small as 0.02 or 0.04. Our data reveal a strong MPCR effect, but almost no group–size effect. Our data demonstrates that, even in large groups and for low MPCRs, considerable contributions to public goods can be expected. Interestingly, the contribution patterns observed in large and very small groups are very similar. To the best of our knowledge, this study is the first one that includes large–group laboratory experiments with a small MPCR under conditions comparable to previous small–group standard public–good experiments. (JEL C91, C72, H42).

I. Introduction

The private provision of public goods is one of the most intensively investigated issues in experimental economics. There are several reasons why public goods receive this much attention. First, the Nash-equilibrium outcome of the public good game is inefficient. Subjects in a public good experiment are confronted with the dilemma that behaving in an individually rational and selfish way does not result in the collectively rational (i.e., efficient) allocation. This makes the game very interesting from a behavioral point of view. If the classical assumption that subjects always behave strictly rationally in their pure selfinterest is dropped, the question arises, whether non-selfish and/or boundedly rational subjects might find a way to escape the social dilemma generated in a public good game.

A second reason for the prominence of public good experiments is that the provision of public goods is crucial in many real world environments. Climate protection, the security of energy supply, the security of basic social systems, or the preservation of cultural heritage are examples of public goods that can only be provided if many people are willing to contribute voluntarily. Accordingly, the economics of public goods has a very strong political impact and the long history of public good experiments[1] can be characterized as a part of the search for solutions for many real world problems. But there is a fundamental difference between real world public goods and their experimental representation in the laboratory. Experiments are run with small groups of three to ten subjects while real world public goods involve much larger groups. This deficiency led us to look for a way to run large group laboratory experiments under conditions comparable to small group standard public good experiments.

The group size has an impact on the production technology of the public good. For small groups the marginal per capita return (MPCR) has to be rather large. To demonstrate this, we use the payoff function employed in standard linear publicgood experiments. Let z_i denote the endowment of subject i, b_i the individual contribution to the public good, and p the marginal return on those parts of the endowment not invested in the public good.

The parameter a measures the marginal productivity of the public good and N denotes the number of subjects. The payoff function for subject i is then given by:

$$\Pi_i = (z_i - b_i)\, p + \frac{a}{N} \sum_{j=1}^{N} b_j \tag{1}$$

$$\text{with } a > p > \frac{a}{N} \tag{2}$$

$$\text{and } MPCR = \frac{a}{Np} \tag{3}$$

Condition (2) ensures that (1) describes an N–person prisoner's dilemma. If we normalize $p = 1$ it follows that the MPCR has to be larger than $1/N$. This means that the return a subject gets from his own investment in the public good is bounded from below by $1/N$.

In a four–subject group the return has to be greater than 0.25 (25 percent of p) and even in relatively large experimental groups of ten the return still has to be larger than 0.10 (10 percent of p). This stands in a sharp contrast to real–world situations, in which very often the personal return from a contribution to public goods is negligible. The most striking examples for extremely low MPCRs are environmental public goods. Imagine that you invest in a more energy–efficient refrigerator or a less CO_2–emitting car in order to help in stabilizing the climate system. Obviously, the MPCR of such an investment is very close to zero – it may, in fact, even be zero (e.g., in the case that the present generation does not profit from contributions, but future generations do). Notice that for an MPCR equal to zero equation (1) turns into:

$$\Pi_i = (z_i - b_i) \tag{4}$$

and (4) is no longer the payoff function of a N–person prisoner's dilemma, but that of a dictator game. This demonstrates very clearly that real public good problems may differ

fundamentally from those established in the laboratory.

The issue is whether the difference between public good experiments with small groups and a large MPCR and real–world public good environments with large groups and a small MPCR is of behavioral importance. To answer this question, we have to find out how the large group size and the small MPCR affect individual contributions to public goods. There are two seminal papers dealing with group–size effects and the role of the MPCR in publicgood experiments.

Isaac and Walker (1988) examine the MPCR effect and the group–size effect for small groups. They ran experiments with groups of four and ten subjects using MPCRs of 0.30 and 0.75. Their main finding is that with the higher MPCR there was no group–size effect, while with the lower MPCR, the larger groups invested more than the smaller groups. For both group sizes, lowering the MPCR led to a sharp decrease of contributions. This effect was stronger for the four–subject groups than for the ten–subject groups.

Isaac, Walker and Williams (1994) are the first to run public good experiments with large groups of 40 and 100 subjects. Dealing with such a large number of subjects is a logistical problem. Laboratories are usually too small to conduct experiments in which 40 or even 100 subjects decide simultaneously under identical conditions. To solve this problem Isaac et al. conducted so–called 'multi–session' experiments. Subjects did not decide simultaneously in a laboratory, but they had to sequentially enter their individual decisions into a computer terminal. This required decision rounds to last for several days. A second modification of the standard procedure concerned the earnings which were "based on extra–credit points rather than cash" (p. 5). The experimental earnings were transformed into a relative performance measure between zero and one. This measure was multiplied by three to determine the number of extra credits earned by subjects. They conducted 21 experiments with groups of 40 and 100 subjects, using the same MPCRs (0.30 and 0.75) as in Isaac and Walker (1988). More concretely, they conducted six multi–session experiments with groups of 40 for each of the two MPCRs, three multi–session experiments with groups of 100 for each of the two

MPCRs, and three single–session experiments with monetary payoffs with groups of 40 and an MPCR of 0.30. They observed neither a group–size nor a MPCR effect. In addition, Isaac et al. ran 53 experiments with groups of four and ten subjects as multi–session experiments, as well as six single–experiments with monetary payoffs for groups of ten subjects. They found that in these small groups the MPCR effect was still at work as described in Isaac and Walker (1988). Isaac et al. also conducted seven experiments with groups of 40 and an MPCR of 0.03. These are of particular interest to us, since our focus is on the behavior of large groups facing a very small MPCR. Isaac et al. ran one of the seven experiments as a single–session laboratory experiment with monetary payoffs. The other six were conducted as multi–session experiments. They observed that cooperation dropped dramatically in the multi–session experiments with an MPCR of 0.03. In the one laboratory experiment with monetary payoffs cooperation broke down completely after the fourth round. To the best of our knowledge, this is the only one observation in a standard laboratory setup reported so far for a relatively large group of 40 subjects and a low MPCR of 0.03.

At the time Isaac et al. conducted their experiments the multi–session design was the only possible way to solve the logistical problems associated with large–group experiments. Nevertheless, the multi–session design has some unavoidable disadvantages. Among others, there is no control of possible communication between subjects. This makes it difficult to directly compare the multi–session experiments with standard lab experiments. In the last years new technical opportunities have opened up that might help to circumvent these disadvantages. In our study, we use the Internet to connect experimental laboratories located at four different universities to get what we call a "connected lab" in which we conduct public good experiments with 60 and 100 subjects. That is, similar to standard public good experiments with small groups, all of our subjects are seated in a laboratory and decide simultaneously.[2] The only difference is that not all subjects are located at the same laboratory. We test with small groups of eight subjects whether it makes a difference if all subjects are located in one laboratory or if they are distributed over the four labs.

Using a connected lab not only allows examining large groups without the disadvantages of multi–session experiments, it also captures a further property of large–group public good problems: In reality, those groups are not concentrated in a small region, but are distributed over several locations. There may be idiosyncratic preferences or modes of behavior in the different locations which are aggregated in the overall provision of the public good. The same is true in the case of connected laboratories.

To the best of our knowledge, we are not only the first to conduct large–group laboratory experiments with a small MPCR under conditions that are comparable to those under which hundreds of small–group standard public good experiments have been performed. We also are the first to systematically compare behavior in large groups with different group sizes and different small MPCRs based on a reasonable number of observations.

II. Research questions

The first question to answer is, whether it makes a difference if subjects make their decisions in a connected laboratory or in a local laboratory. Because of the logistical problems already mentioned, it is not possible to conduct large–group experiments both in connected and local labs. Therefore, we use small groups of eight subjects to test for behavioral differences between a connected–lab treatment, in which subjects are distributed over the four labs (two subjects per lab), and a local–lab treatment. We formulate the following hypothesis.

H1: It makes no behavioral difference whether we use a connected or a local lab.

Our second research question concerns the role of group size and MPCR in large groups. Isaac et al. (1994) observed in the multi–session design that large groups facing a very small MPCR of 0.03 behaved similarly to large groups facing a high MPCR of 0.3 or 0.75. Furthermore, they found that there is no difference in contributions made by large groups of different sizes (40 or 100). We should thus neither observe a group size nor a MPCR effect in our experiments with large groups.

H2a: In the comparison of contribution behavior in large groups (of 60 or 100), we should observe no group–size effect.

H2b: In large groups (of 60 or 100), there is no MPCR effect, when we compare very small MPCRs (0.02 and 0.04).

Our third research question is whether large groups facing very small MPCRs will be able to cooperate at all. Given the findings of Isaac et al. (1994) in the case of an MPCR equal to 0.03, we should expect a very low degree of cooperation.

H3: Large groups (of 60 or 100) facing a very small MPCR (of 0.02 or 0.04) show very low cooperation rates.

Additionally, it is an interesting question how large groups facing a very small MPCR perform in comparison with small groups facing a large MPCR, because this gives us some evidence of whether or not the results of hundreds of small–group experiments teach us something about what happens in real public good situations with large groups and small MPCRs. If, for example, large groups show very low cooperation rates, this would imply a serious challenge for the experimental research on public goods conducted so far.

III. Experimental design

In all of our treatments, a standard linear ten–round public good game was played. The payoff function was identical to (1) with $p = 1$. The initial endowment in each of the ten rounds was 120 Eurocent. The MPCR was 0.02 and 0.04 for both group sizes of 60 and 100 subjects and 0.25 for the small groups of 8, which we used in our control treatments. The treatments with large groups were run simultaneously in the laboratories of the Universities of Bonn, Duisburg–Essen, Göttingen, and Magdeburg (all of them located in Germany, see Figure 1), which were connected via the Internet. In the treatments with group size 100 (60), on average 25 (15) subjects participated in each laboratory. All treatments were coordinated by the laboratory in Magdeburg. The communication between laboratories was run via Skype. When entering the respective laboratory, subjects could see a (soundless)

video conference of the four laboratories on a computer screen. Thus, each subject had the opportunity to verify that all laboratories were indeed connected and worked simultaneously.

At the beginning of each treatment, subjects received written instructions (see Appendix A). Before the start of the first round of the public good game, they had to answer several questions concerning the payoff rules of the game in order to ensure that they had understood the game correctly. After each round, subjects were informed about the amount they kept, their own contribution, and the average contribution of all group members to the public good, their individual payoff from the public good, their individual earnings in the last round, and the cumulated earnings over all previous rounds. They knew that after ten rounds the experiment would be finished. Subjects were then paid in cash and left the laboratories. The sessions lasted about 90 minutes and the average earning was 15.36 Euro. The experiment was programmed using zTree (Fischbacher 2007) and the recruitment of subjects was operated by Orsee (Greiner 2004).

Figure 1: The location of the four laboratories in Germany.

We conducted six different treatments and collected data for eight groups (independent observations) per treatment (Table 1). The first two treatments (*T1* and *T2*) were run as

Treatment	Treatment name	Group size (average)	MPCR	Sessions /# of ind. obs.	Lab
T1	$8-0.25L$	8(8)	0.25	8	local
T2	$8-0.25$	8(8)	0.25	8	connected
T3	$60-0.02$	60(60)	0.02	8	connected
T4	$60-0.04$	60(60)	0.04	8	connected
T5	$100-0.02$	100(100)	0.02	8	connected
T6	$100-0.04$	100(95.5)	0.04	8	connected

Table 1: Treatment Conditions

control treatments and test whether the connected–lab design has any influence on subjects' decisions. In *T1* ("$8-0.25$-local"), we used an MPCR of 0.25 and local groups of eight subjects; that is, each laboratory locally collected data of eight independent groups each consisting of eight subjects. In T2 ("$8-0.25$–connected"), we again used an MPCR of 0.25 and group size eight. But this time there were two subjects in each of the four laboratories and formed a group of eight in the connected lab.

In our large–group treatments (*T3* to *T6*), subjects were distributed over the four laboratories. In *T3* ("$60-0.02$") and *T4* ("$60-0.04$"), groups of 60 subjects played the public good game facing a MPCR of 0.02 and 0.04, respectively. *T5* ("$100-0.02$") and *T6* ("$100-0.04$") were run with groups of 100 and a MPCR of 0.02 and 0.04, respectively. Because of no–shows, the number of 100 subjects per group could not always be reached. In *T6*, the average number of subjects was 95.4 .[3] In total $2,840$ subjects participated in the experiment. Table 1 summarizes the treatment conditions.

IV. Results

A critical assumption in our study is that the connected–lab design has no influence on subjects' behavior (Hypothesis *H1*). Based on the comparison of *T1* and *T2*, we test this hypothesis, which cannot be rejected.[4] That is, there is no significant difference regarding average contributions made over all ten rounds and average contributions made in each of the rounds between local groups and groups in the connected lab ($p \geq 0.80$, two–sided Mann–Whitney–U tests), see also Figure 2. From a methodological point of view this finding is good news, because it appears that the capacity of laboratories can be multiplied by connecting

them.

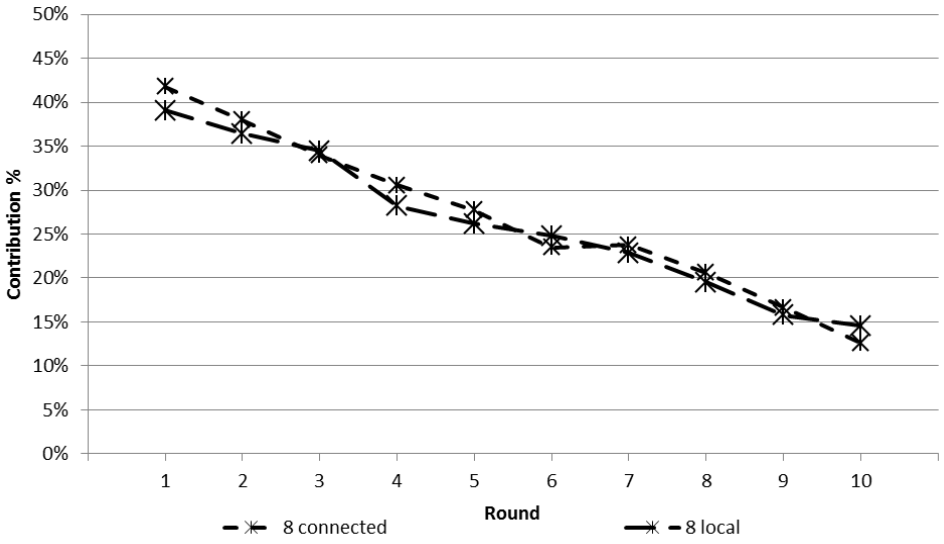

Figure 2: Average contributions to the public good in *T1* and *T2*.

Hypotheses 2a and 2b specify that there is neither a group–size nor a MPCR effect in large groups. Figure 3 shows the average share of the endowment invested in the four large–group treatments *T3* to *T6*.

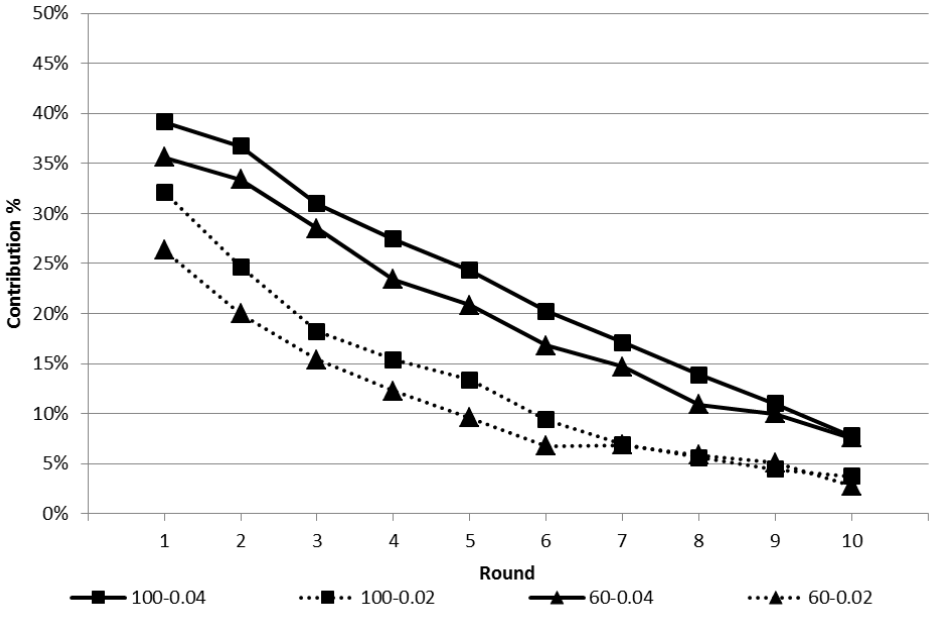

Figure 3: Average contributions to the public good in treatments *T3* - *T6*.

	Round										
Comparison	1	2	3	4	5	6	7	8	9	10	Total
T5 (100 - 0.02) vs T6 (100 - 0.04)	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.049**
T3 (60 - 0.02) vs T4 (60 - 0.04)	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.023**
T3 (60 - 0.02) vs T5 (100 - 0.02)	**0.009**	**0.004**	0.357	0.149	**0.011**	0.165	0.197	**0.002**	**0.04**	0.295	0.650
T4 (60 - 0.04) vs T6 (100 - 0.04)	0.980	0.105	0.199	**0.011**	**0.016**	0.155	0.212	0.148	0.964	0.154	0.496

Table 2: Round-by-round comparison of treatments T3 - T6

Hypothesis *H2a* (group size) cannot be fully rejected as the following test results show (see Table 2 for p–values). While the comparison of group sizes 100 and 60 for each of the two MPCRs reveals no significant differences with respect to average contributions made in all ten rounds ($p = 0.65$ for *T3/5* and $p = 0.496$ for *T4/6*, two–sided Mann–Whitney U–tests), a round–by–round comparison shows that, for an MPCR of 0.04 (0.02) the smaller groups contribute significantly less to the public good in 2 (5) of the ten rounds. The observed magnitude of differences between group sizes 60 and 100 is rather small, though.

Hypothesis *H2b* (MPCR) can be clearly rejected, however, we observe a strong MPCR effect for both group sizes. Average contributions in the low–MPCR treatment *T5* are significantly lower than those in the high–MPCR treatment *T6* in all ten rounds (see Table 2). The same is true when comparing *T3* and *T4*.

For the interpretation of these observations, it is important to consider that the overall impact of an individual contribution depends on both the MPCR and the group–size. With an MPCR of 0.04 and group size of 60 one Euro spent to finance the public good leads to a total payoff of 2.40 Euro for the group. In a group of 100 the same contribution generates a total payoff of 4.00 Euro. A natural conjecture seems to be that such a difference will have an effect on average contributions, but this is not the case – at least not over all ten rounds.

Our last research question concerns the cooperation in large groups with small MPCR in general. We hypothesize that, based on the observation by Isaac at al. (1994), there will be nearly no cooperation [*H3*]. As Figure 3 clearly demonstrates, large groups cooperate to a remarkable extent, even in the low–MPCR treatments. For the MPCR of 0.04 both groups start at contribution rates of 35% and 39% of the endowment, respectively. In round 10, contributions drop to8% and 7%, respectively.

Figure 4 reveals that our previous results on aggregate behavior in large groups seem to be due to a steadily increasing fraction of strict free–riding behavior, i.e., those who contribute nothing to the public good. Even though for both group–sizes, the percentage of strict free–riding increases round by round, the fraction of strict free–riding is higher in the low–MPCR than in the high–MPCR treatments. This difference is significant only for group–size 100 ($p = 0.034$), though.

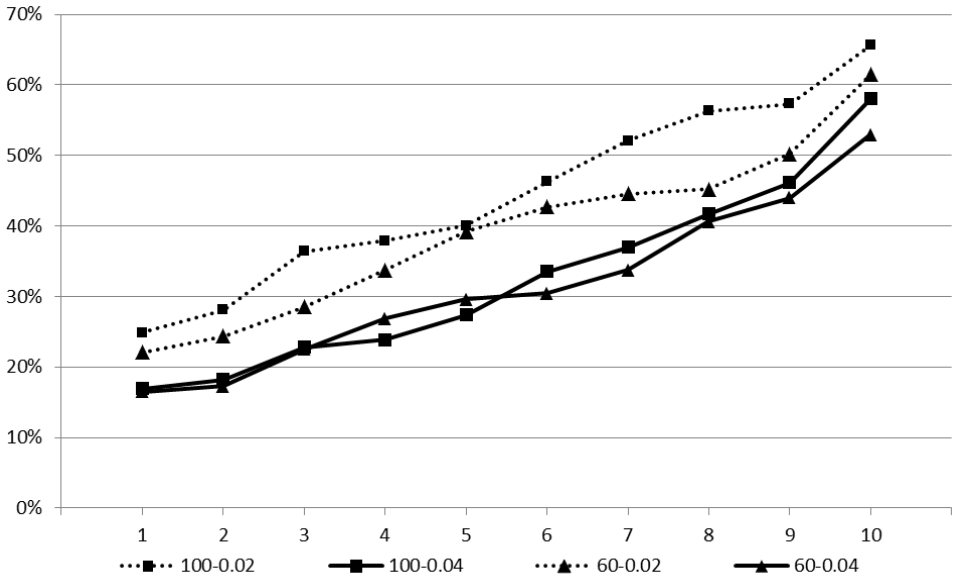

Figure 4: Percentage of strict free riding in *T3* - *T6*.

Finally, we are interested in how large groups facing a small MPCR perform in comparison with small groups facing a large MPCR. Figure 5 illustrating average contributions made in treatments $100 - 0.04$ and $8 - 0.25$–connected reveals a surprising observation: Not only are the overall amounts contributed to the public good by a single subject on average nearly

the same, but the contribution pattern is also very similar. In both treatments, contributions decrease round by round at nearly equal rates. We can only state that contributions in both treatments neither significantly differ overall nor round by round, but we are not able to analyze the interaction between the MPCR effect and the group–size effect, which leads to this surprising result. We will come back to this issue in the discussion section.

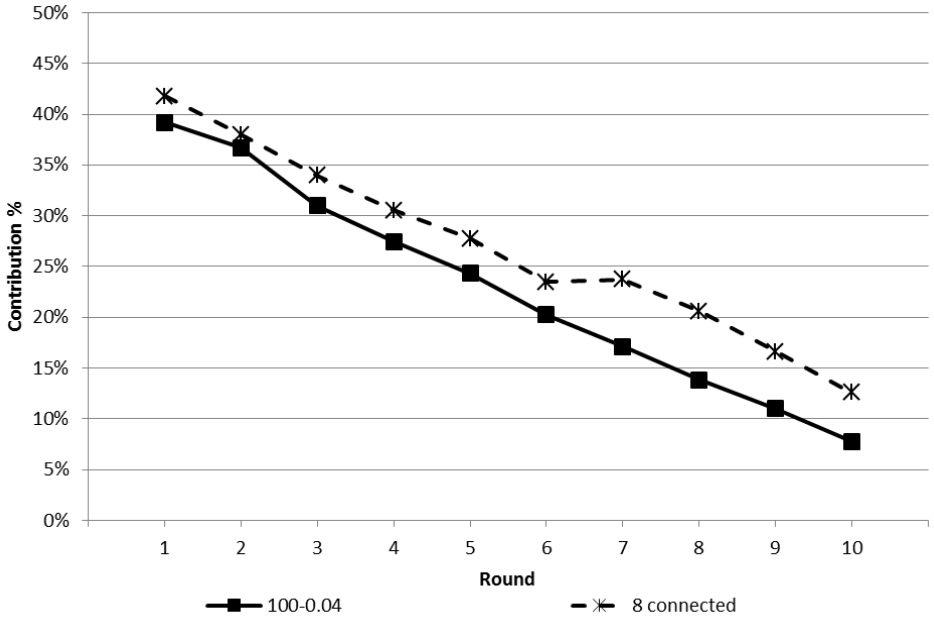

Figure 5: Average contributions to the public good in treatments *T2* and *T6*.

V. Discussion

In his famous survey, Ledyard (1995) remarked that we do not know what happens in large groups if they are confronted with a publicgood problem. Sixteen years later this still holds true, particularly for situations that resemble many real world public good problems. Using the connected lab, we are the first to conduct laboratory experiments with large groups and a small MPCR under conditions comparable to small–group standard public good experiments. On the basis of previous research it is not clear whether, under laboratory conditions, large groups facing a very small MPCR will be able to cooperate at all. Isaac, Walker and Williams (1994) observed very low cooperation rates even in a relatively "small" large group of 40 subjects.

Having this observation in mind, the results reported in this paper come as a surprise. The first surprise is that, although the MPCRs are extremely small, large groups react very sensibly to variations of this parameter. If only two instead of four cents per Euro are paid, cooperation decreases significantly. On the other hand, subjects in large groups do not care much about group size, i.e. whether the MPCR is paid 60 times or 100 times.

This last observation indicates that subjects' decisions in large groups are not affected that much by the overall impact a contribution to the public good has. This impact depends on both, the MPCR and the number of subjects who benefit from a contribution. Contributions in large groups seem to be influenced primarily by the former. That is, subjects do not care that much about others' benefits due to their own contribution, but about their own personal return. But, if this really is the case, why do subjects put money in an asset that only pays two or four percent given that there is an alternative available paying 100 percent? We cannot answer this question on the basis of our experiment, but a possible answer could be that the payoff a subject gets from her or his own investment has the function of a catalyzer that induces cooperation. Subjects may perceive the MPCR as a kind of reward they get if they behave cooperatively.[5] This reward may be very small, but obviously it is important to get one.

The second surprise is that large groups do cooperate in a significant way. The cooperation rates in the groups facing an MPCR of 0.04 are of the same magnitude as those known from experiments with small groups and large MPCRs. Also, the pattern with which contributions decrease from round to round looks very similar to the corresponding contribution paths observed in small–group experiments. It was not a central interest of ours to explain why the contribution patterns are that similar. The difficulty with respect to this comparison is that the two groups differ in two dimensions, the group size and the MPCR. It is neither possible to run experiments with small groups and a very low MPCR (for reasons related to the parameter constraint on linear public good games guaranteeing that full contribution is the social optimum) nor with large groups and a high MPCR (for financial reasons). Even if

one were willing (and able) to pay the extremely high payoffs in a large–group high–MPCR experiment, the efficiency gain of contributing to the public good would be much higher than that for any small–group experiment ever conducted. Thus, we could only examine whether large groups facing a small MPCR behave less cooperatively than the small groups that are usually used, but we cannot clearly trace back any of our results to a MPCR effect and/or a group–size effect. To do this, we have to learn much more about the interaction of the MPCR effect and the group size effect. Therefore, we have to delegate the answer to future research. But given our results, there seems to be good reason to be optimistic that the many small–group experiments are not irrelevant for the understanding of large–group behavior.

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Notes

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[1]See Ledyard (1995) for an early overview.

[2]Note that we did not conduct a so-called 'internet experiment', in which subjects decide in a decentralized way at their home computers

[3]Since each individual decision in the first round is an independent observation, we can check if groups of less than (but close to) 100 behaved differently from those with exactly 100 subjects and we found no significant difference ($p > 0.39$ two-sided Mann-Whitney-U tests)

[4]All data are available at http://www.ovgu.de/vwl3/experiments/pg_large_groups/

[5]This is corroborated by the protocols of a video experiment by Brosig-Koch, Dittrich and Hennig-Schmidt (2011).

A Appendix

Instructions 100

Prelimenary: You are participating in an economic experiment focusing on decision

making. If there are any questions left after having read these instructions or during the experiment, please raise your hand. We will then come to your cubicle.

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

You are part of a group of 100 participants. These 100 people are located in four experimental laboratories across Germany, connected via internet. All group members received the same instructions. Moreover, the laboratories are connected via a video connection. If you have any doubts about this procedure, please take a look at our video conference!

You and the other 99 group members are facing the following identical decision situation during 10 consecutive rounds: In each round, you receiven an endowment of 120 Euro Cent. You decide how much of this endowment you want to "keep", and how much you want to "contribute". Each contribution x is creating an amount $0.02x$ for each group member (including the contributor). That means that for every Euro Cent you contribute, the whole group will be paid 2 Euro Cent ($0.02 \cdot 100$). For each Euro Cent you do contribute, you will be paid 0.02 Euro Cent like all other group members. That part of your endowment that you do not contribute (i. e. that you "keep"), you keep for yourself.

Summing up in one formula, your earnings in Euro Cent per round are as follows:

120 – Your Contribution +0.02 x (Sum of all group members' contributions)

Please note that your contribution per round can be any amount between 0 and 120 Euro Cent and that all group members are facing an identical decision situation. After each round you will be informed on the amount you kept, your contribution, the average contribution of all 100 group members, your payoff based on the contributions of all group members, your payoff in the respective round and your payoff cumulated over all periods. Moreover, you will see a table listing the same information for all previous rounds.

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

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

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