FAERE
French Association
of Environmental and Resource Economists

Working papers

Beyond perfect substitutability in public good games: heterogeneous structures of preferences

2017 FAERE Prize

Marion Dupoux

WP 2017.21

Suggested citation:

M. Dupoux *(2017).* Beyond perfect substitutability in public good games: heterogeneous structures of preferences. *FAERE Working Paper, 2017.21.*

ISSN number: **2274-5556**

www.faere.fr

Beyond perfect substitutability in public good games: heterogeneous structures of preferences

Marion Dupoux[a]

Abstract

The literature on public good games is very focused on the additive separability of the values of the private and the public goods. Yet, the additive structure underlies a perfect substitutability relationship between private and public goods, which is a strong assumption. This paper studies the effect of payoff/preference structures on contributions to the public good within a voluntary contributions experiment in both homogeneous and heterogeneous groups. Within the structure of substitutability, I find that subjects free-ride more often when they interact with subjects of the other type (complementarity) for whom it is optimal to contribute. Introducing such a heterogeneity may provide a method for the identification of free-riders. Nonetheless, an advantageous inequality aversion emerges as well. This means that under perfect substitutability, subjects tend to dislike earning too much compared to their group member whose payoffs underlie complementarity, a more constraining structure.

Keywords: structure of payoffs, public good game, substitutability, complementarity, heterogeneity, free-riding, inequality

JEL Classification: C71, C90, C92, D70, H41

[a]Department of Economics, University of Gothenburg, PO Box 640, 40530 Gothenburg, Sweden. Tel +46 31 7862641.

1 Introduction

Public good games are mostly linear in the literature, which means that both private and public goods generate constant returns. Linear games are characterized by boundary Nash equilibrium and social optimum. This is at odds with the observation of positive contributions in the lab (Vesterlund, 2016) and considered as not realistic (Cason and Gangadharan, 2015). It partly explains the switch from linear to nonlinear games, the latter inducing interior Nash equilibrium. In the literature, the main forms of nonlinearities are the piecewise linear form (*e.g.* Bracha et al. (2011), Cason and Gangadharan (2015)), quadratic returns to the private and/or the public good (*e.g.* Sefton and Steinberg (1996)) and Cobb-Douglas payoff functions (*e.g.* Andreoni (1993) and Cason et al. (2002)).

Beyond the linear structure of public good games, all linear and most nonlinear games[1] involve an additivity of the private and the public goods returns. This additivity underlies a perfect substitutability[2] between private and public goods, which constitutes a strong assumption. Yet, the literature on public economics gives importance to the relationship between private and public goods *e.g.* Karras (1996) and Fiorito and Kollintzas (2004) regarding general private and public consumptions, Neumayer (1999), Gerlagh and Zwaan (2002) and Traeger (2011) regarding private consumption and environmental quality. In particular, most negotiations are characterized by an interaction between agents who have different *structures of preferences/payoffs*. In the context of climate change prevention for example, impacts are heterogeneous across countries (Burke et al., 2015; Sterner, 2015), which leads to different (political) preferences. On the one hand, some countries may find advantageous to prevent climate change because it may enhance their economic aims, *i.e.* preventing climate change and improving GDP are rather *complementary*. This is mostly the case of vulnerable countries like those settled on islands. On the other hand, some countries have less interest in preventing climate change, especially those which are at high latitudes. Russia could for example save energy consumption and exploit more lands if the planet warms up, hence the *substitutability*. Therefore it is fundamental to account for the way private and public goods combine to provide utility.

In this paper, I investigate the effect of the structure of payoffs in both homogeneous and heterogeneous groups, on the rate of overcontribution[3] compared to the Nash and on cooperation. I analyze behavioral determinants in the two following treatments: whether agents interact with the same or a different type of agent in terms of their payoff structure.

Two structures of payoff are considered: perfect substitutability and complementarity. The two structures are generated from a constant elasticity of substitution (CES) utility function but differ according to the value of the elasticity of substitution. The two structures are first evaluated separately in a between-subject homogeneous treatment. Then, the two structures

[1] Including piecewise functions and quadratic returns.

[2] In the sense of Hicks. The additivity reflects independence in the Edgeworth-Pareto sense.

[3] Contributions cannot be compared directly since the Nash equilibrium across treatments changes. This will be explained in Section 3

are crossed in a within-subject treatment. Put differently, subjects are attributed a structure of payoffs (*i.e.* a type) for the whole experiment and meet in one stage subjects with the same payoff structure, and in another stage subjects with a different payoff structure.

The structure of payoffs is inherently linked to the strength of the social dilemma[4] as defined by Willinger and Ziegelmeyer (2001). Perfect substitutability which is underlied by a linear public good game involves the strongest social dilemma since individual and collective interests are at opposite boundaries. The more the structure is moved away from perfect substitutability (or equivalently additivity) the weaker the social dilemma, because both the Nash and social strategies move to the interior of the choice space. As in Willinger and Ziegelmeyer (2001), it is then possible in my experiment to analyze whether overcontributions persist *(i)* in a non-additive design and *(ii)* when heterogeneity of payoff structures is introduced.

This is the first paper which introduces heterogeneous structures of payoffs within a public good game in the form of voluntary contributions. There are a few non-additive structures in the literature but either it involves homogeneous groups of subjects (Andreoni, 1993; Cason et al., 2002) or a heterogeneity in terms of endowments or returns to the public good (Chan et al., 1999). Also, this paper is the first to link contributions to the public good and the substitutability between private and public good. This puts forward the inherent, yet overlooked, assumption on substitutability *vs.* complementarity between private and public goods involved in the choice of the functional form of the game.

A lab experiment run in the University of Gothenburg mid-October 2016 allows me to provide a first insight into the effect of the structure of payoffs on behavior. I find that the structure of payoffs affects the rate of overcontribution. Perfect substitutability is associated with a higher rate of overcontribution and a higher proportion of zero contributions than complementarity.

Within subject's type (substitutability or complementarity), the following result stands out. Under perfect substitutability, free-riding increases in heterogeneous groups compared with homogeneous groups. Indeed, subjects have a higher incentive to free-ride when it is optimal for their group member (players with a complementarity structure) to contribute. This suggests that introducing heterogeneity in the payoff structure provides a method to identify free-riders.

Finally, an advantageous inequality aversion emerges from subjects whose payoffs underlie perfect substitutability when they interact with subjects whose payoffs underpin complementarity. The formers experience aversion to earning too much compared with their group member.

The remainder of the paper is organized as follows: Section 2 explains why substitutability is an important concern and how it is linked to public good games. Section 3 describes the experimental theory and design of the experiment. Section 4 presents preliminary results from the experiment. Section 5 offers preliminary conclusions and perspectives.

[4]This is the relative difference between the Nash equilibrium and the social optimum.

2 Background

2.1 Why substitutability is an important concern in public economics

A large body of empirical literature investigates the relationship between private and public consumptions or investments. It generally differs across countries. Karras (1996) and Fiorito and Kollintzas (2004) find that in the aggregate, private and public consumptions are rather complements than substitutes. On the contrary, Aschauer (1985) and Ahmed (1986) find evidence of substitutability for the respective cases of the United States and the United Kingdom. This relationship is fundamental in that it can affect international negotiations *i.e.* whether to invest or not in a common good.

It is particularly relevant to the climate change issue. Climate change impacts are heterogeneous across countries (Burke et al., 2015; Sterner, 2015), even if in the aggregate, damages are negative. Giraudet and Guivarch (2016) provide a review on this aspect and show that global warming rather is an asymmetric public bad than a uniform one as commonly considered in modelling. The latitude is one central aspect of this heterogeneity: cold regions such as Russia and Canada may benefit from climate change through *e.g.* the development of new agricultural lands, better agricultural yields or lower heating expenditures, while warm regions like most African countries may suffer from more severe droughts and higher expenditures in air conditioning. Indeed, agriculture and energy use stand out as the most non-uniform GHG-related impacts on the economy (Arent et al., 2014).[5] This directly affects the structure of payoffs *i.e.* whether investing in climate change prevention complements or substitutes for country economic aims.

Additionally, theoretical works show the impact of the substitutability assumption on discounting (Traeger, 2011), which is a key aspect of decision-making be it national or international.

2.2 Substitutability and public good games

The perfect substitutability assumption is widespread in public good games, particularly those in the form of voluntary contributions. Linear and nonlinear games are reviewed in the following subsections, and classified as additive and non-additive games.

2.2.1 *Linear public good games*

The standard public good game involves linear payoffs *i.e.* where the returns from the private and the public good are constant and add up. Consider an individual i who contributes y_i to the public good out of an endowment of w_i units, thereby consumes $x_i = w_i - y_i$ units of the private

[5] For example, Costinot et al. (2016, p.207) plot the impact of climate change on the predicted relative change in productivity of two crucial crops for food production, namely wheat and rice, to particularly show the heterogeneity both between and within countries.

good. The individual's marginal value from the private good is a constant α, and the one from the public good is another constant β. Then individual i's payoff is given by the following payoff function:

$$\pi_i = \alpha(w_i - y_i) + \beta y \quad (1)$$

where $y = \sum_{j=1}^{N} y_j$ is the sum of all subjects' contributions to the public good. N is the number of subjects. The choice variable is y_i, which represents the amount subject i allocates to the public good. Then βy is the value of the public good and $x_i = w_i - y_i$ is the consumption of the private good. Notice that $\beta < \alpha < N\beta$ is a necessary condition to characterize a social dilemma. Indeed, $\beta < \alpha$ states that private returns are higher than public returns, which makes a zero contribution ($y_i = 0$) to the public good the (dominant strategy) Nash equilibrium. $\alpha < N\beta$ characterizes the social optimum ($y_i = w_i$) which is at the opposite boundary where the overall returns from the public good outweigh the private returns.

Linear structures in voluntary contributions mechanisms (VCM) have the advantage of displaying payoffs in a very simple manner to the experimental subjects. The latters are given the information of how much they earn from the private and the public goods separately since it is basically added-up. As well, free-riders are easy to identify because the Nash equilibrium and the social optimum are at opposite boundaries of the choice space. This structure is attractive by its simplicity but may not be realistic when it comes to real problems.

In the lab, the observation of contributions between 40% and 60% of subjects' endowment (Ostrom, 2000) questions the linear property of public good games, hence the search for more compatible designs with the observed pattern of contributions (Vesterlund, 2016). Therefore, it is worthwhile considering other settings where Nash and social outcomes are not at opposite boundaries *i.e.* non-linear settings.

2.2.2 *Nonlinear (non-additive) public good games*

Nonlinearities have been implemented in various ways in the literature. One simple way is to induce diminishing marginal returns of the private and/or the public goods. Formally, it means that α and β decrease instead of remaining constant as in the linear setting (see Eq. (1)). These nonlinearities are mostly implemented separately (Laury and Holt, 2008). If only α decreases (*i.e.* diminishing marginal value of the private good), the Nash equilibrium remains a unique dominant strategy as primarily studied by Isaac (1991) followed by *e.g.* Keser (1996) and Van Dijk et al. (2002). Quadratic returns are often employed as described below:

$$\pi_i = \alpha_1(w_i - y_i) - \alpha_2(w_i - y_i)^2 + \beta y \quad (2)$$

with α_1 and α_2 two constants and $\beta < \alpha_1$.

If only β decreases (*i.e.* diminishing marginal value of the public good), this turns the Nash equilibrium into a non-dominant strategy.[6]

$$\pi_i = \alpha(w_i - y_i) + \beta_1 y - \beta_2 y^2 \tag{3}$$

with β_1 and β_2 two constants and $\alpha < \beta_1$. Sefton and Steinberg (1996) compare the first type of nonlinearity (dominant Nash strategy) with the second type (non-dominant Nash strategy). They find that the variance of contributions regarding the non-dominant strategy is higher since it is less clear to determine how cooperation can be achieved in such a framework. Globally, there is still an observation of more contributions than the Nash equilibrium predicts (Laury and Holt, 2008), even when the location of the interior Nash equilibrium is moved within the choice space (see Isaac and Walker (1998)[7] and Willinger and Ziegelmeyer (2001)).

Another simple way of introducing nonlinearities is the piecewise linear form of public returns as Bracha et al. (2011) and Cason and Gangadharan (2015) use in their respective experiments. The cost of contributing is increasing in a discrete manner as contributions increase. It induces both an interior social optimum and a dominant-strategy unique Nash equilibrium.

$$\pi_i = w_i - cost(y_i) + return(y) \tag{4}$$

with

$$cost(y_i) \begin{cases} \delta_1 y_i & \text{if } y_i \in [0, NE] \\ \delta_1\ NE + \delta_2\ y_i & \text{if } y_i \in [NE, SO] \\ \delta_1\ NE + \delta_2\ SO + \delta_3\ y_i & \text{if } y_i \in [SO, w_i] \end{cases}$$

and

$$return(y) \begin{cases} 0 & \text{if } y < FC \\ \beta y & \text{if } y \geq FC \end{cases}$$

where $0 < \delta_1 < \beta < \delta_2 < 2\beta < \delta_3$ (increasing cost of contributing), NE and SO are the Nash and social contributions, and FC is a fixed cost which conditions the provision of the public good.

The common pool resource allocation literature focused on nonlinearities as well (Ostrom et al., 1992). But the additivity is a rule which also applies to most of this type of games.

All these types of nonlinear designs are very focused on the interior Nash equilibrium, which is an important concern regarding the observation of overcontributions in the lab for example. Nonlinear games allow for interior Nash equilibrium. However, as linear games, most of them are additive *i.e.* private and public returns are additively separable, which is a strong assumption. This raises the question of the relationship between private and public goods which is at the core of the literature in public economics (*e.g.* environment, health, investment). Closer to functions employed in theoretical works, Andreoni (1993) uses a Cobb-

[6] In other words, the strategy depends on the others' contribution.

[7] Except for very high positions of the Nash equilibrium. Still undercontributions for the high treatment were smaller than overcontributions in the other lower treatments, which indicates a propensity to cooperation.

Douglas function to assess crowding out. He imposes a minimum required contribution (like a tax) for each individual in order to move the boundary toward the Nash equilibrium and finds that the contributions increase but by less than the amount of the tax, hence the partial crowding out effect. Cason et al. (2002) also use a Cobb-Douglas function to study spitefulness across Japanese and American subjects. They find that American subjects are very close to the Nash predictions. Chan et al. (1999) use a linear function to which they add a Cobb-Douglas component to study the effect of heterogeneous[8] agents on aggregate contributions. As highlighted in subsection 2.1, many situations involve the interaction of individuals with different payoffs, not only regarding their endowment or the return they get from investing in a public project, but in the structure of their payoffs. This structure inherently makes the magnitude[9] of the social dilemma vary. When one shifts away from additive separability of the private and the public values, both the Nash equilibrium and the social optimum move away from the extremes ends of the choice space.

3 Experimental environment

3.1 Theory

Two subjects 1 and 2 decide how much to contribute to a public good.[10] They are initially endowed with w_i where $i = 1,2$ that they have to allocate either to the public good y or to their own consumption of the private good $x_i = w_i - y_i$. The total provision of the public good hence results in $y = y_1 + y_2 + q$ where q is an initial exogenous quantity[11] of the public good and where y_1 and y_2 are the respective subjects' contributions. A utility-maximizer in this framework has the following decision problem:

$$\max\ u_i(x_i, y) \text{ s.t. } x_i + y_i = w_i \tag{5}$$

with u_i subject's i utility function. Subjects are distinguished according to their (supposed or attributed) preference structure (either substitutability or complementarity between the private and the public goods). To achieve this, I use an integer-approximation of a CES payoff function to convert contributions to the two different goods into each participant's payoffs:

$$u_i(x_i, y) = (\alpha\, x_i^{1-\frac{1}{\varepsilon_i}} + (1-\alpha)\, y^{1-\frac{1}{\varepsilon_i}})^{\frac{\varepsilon_i}{\varepsilon_i - 1}} \tag{6}$$

[8] In terms of endowment and returns to the public good.

[9] Or strength, as put forward by Willinger and Ziegelmeyer (2001).

[10] I chose to run a two-subject experiment as in Cason et al. (2002) or Van Dijk et al. (2002) who also use payoff tables. The use of payoff tables involves that the size of the table increases in the number of players, which would make the payoff table more complicated to read.

[11] q only allows me to ensure that there is a unique Nash equilibrium in the payoff table.

where ε_i is the constant elasticity of substitution between x_i and y for subject i, α is the return from private consumption. ε_i is varied across a 2×2 treatments design as shown in Table I.

Table I: Treatments according to the payoff structure

payoff structure	ε value	S	C	$S \times C$	$C \times S$
Substitutability	$\varepsilon_i > 1$	×		×	×
Complementarity	$\varepsilon_i < 1$		×	×	×

[a] S and C are between-subject treatments. Subjects are attributed a type (either S or C) during the whole experiment.
[b] S / $S \times C$ and C / $C \times S$ are within-subject treatments. Subjects both experience a treatment in homogeneous groups (S, C) and heterogeneous groups $S \times C$ and $C \times S$.

When ε_i tends to infinity, the CES payoff function reduces to a linear public good game as presented in subsection 2.2.1, which underlies perfect substitutability between the private and the public goods. When $\varepsilon_i = 0$, the CES function reduces to the Leontieff function. This boundary case is not considered in the analysis because it does not generate any social dilemma (*i.e.* the Nash equilibrium is socially-efficient). However when ε_i is less than 1, a large degree of complementarity between goods is generated. Note that a Cobb-Douglas function relies on $\varepsilon_i = 1$,[12] which is an intermediate case between perfect substitutability and perfect complementarity.

To simplify notations, I denote by $\gamma_i = 1 - \frac{1}{\varepsilon_i}$ such that the CES utility function can be rewritten as:

$$u_i(x_i, y) = (\alpha\, x_i^{\gamma_i} + (1-\alpha) y^{\gamma_i})^{\frac{1}{\gamma_i}} \tag{7}$$

Using a monotonic transformation for the experiment, the payoff function results in:

$$\pi_i(x_i, y) = C + \left((\alpha\, (w_i - y_i)^{\gamma_i} + (1-\alpha)(y_i + y_{-i})^{\gamma_i})^{\frac{1}{\gamma_i}} \right)^{\eta} \tag{8}$$

where C and η are positive constants.

Despite the large body of literature on public good games which reports overcontributions compared to the Nash equilibrium, the traditional theory of pure self-interested individuals is retained as a benchmark in this experiment. As shown in Appendix A, the Nash equilibrium results in the following contributions:

$$\forall\, i\; y_i^* = \frac{1}{1 + \mu_i + \mu_{-i}} \left((1 - \mu_i + \mu_{-i}) w - \mu_i\, q \right) \tag{9}$$

with $\mu_i = \left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\gamma_i - 1}}$ and $w = w_i = w_{-i}$ by assumption. $-i$ denotes the individual in the

[12] *E.g.* Andreoni (1993) and Cason et al. (2002) use Cobb-Douglas payoff functions.

same group as subject i.

In the homogeneous case (treatments S or C), $\gamma = \gamma_i = \gamma_{-i}$ (hence $\mu = \mu_i = \mu_{-i}$), resulting in:

$$y_1^* = y_2^* = \frac{1}{1+2\mu}(w - \mu\, q) \tag{10}$$

Regarding the Pareto efficient outcome,[13] let θ be the share of subject i's contribution. The general case in which participants are heterogeneous in terms of their payoff structures ($S \times C$ and $C \times S$ treatments)) is determined by the pair (θ, y) which satisfies the following equation and is represented in Figure 7 in Appendix B for the parameters values of the experiment reported in Table II.

$$y^{\gamma_1 - 1}\left(w\theta(y-q)\right)^{1-\gamma_1} + y^{\gamma_2 - 1}\left(w - (1-\theta)(y-q)\right)^{1-\gamma_2} = \frac{\alpha}{1-\alpha} \tag{11}$$

Table II: Utility Function Parameters Value Common to all Treatments

Parameter	Value
w	12
α	0.595
q	0.1426

In the homogeneous case, θ is considered equal across the two participants pertaining to the same group, which leads to the following social optimum:

$$y_1^{s.o.} = y_2^{s.o.} = \frac{1}{2}(y^{s.o} - q) \tag{12}$$

where $y^{s.o} = \frac{(\theta\, q+w)(2(1-\alpha))^{\frac{1}{1-\gamma}}}{\alpha^{\frac{1}{1-\gamma}} + \frac{1}{2}(2(1-\alpha))^{\frac{1}{1-\gamma}}}$ (see Appendix B).

Though, in practice in the literature on public good games, the social optimum is determined by the maximum of the sum of individuals' payoffs. In the heterogeneous case, the social optimum corresponds to the highest Pareto efficient optimum.

3.2 Experimental treatments

The experiment includes a 2×2 design. For each type of subject (S or C), the homogeneous treatment implies that a group is composed of two subjects with identical payoff functions (same type). In Treatment S (for substitutability), both subjects have linear payoffs. Treatment

[13] This is determined by the Samuelson condition and the feasibility condition as detailed in Appendix B.

C is characterized by complementarity between the public and private goods. The preference structure (hence payoffs structure) is the same for both subjects as well.

Conversely, the two other treatments, namely $S \times C$ and $C \times S$, are characterized by groups of two subjects with different payoff structures (different types). One subject decides how much to contribute to the public good upon linear payoffs (type *S*) while the other one has payoffs characterized by complementarity (type *C*).

Treatment *S* reduces to a standard homogeneous linear public good game. It is the baseline treatment of the experiment with $\varepsilon_1 = \varepsilon_2 = 1000$.[14] The Nash equilibrium and the social optimum are at opposite boundaries: free-riding (*i.e.* contributing zero to the public good) is the best self-interested strategy whereas contributing everything is socially optimal. The Nash equilibrium is a dominant strategy in this treatment. Since returns from the private and the public goods are additive, they are usually displayed separately in the literature *i.e.* gains from the private good and gains from the public good. In my experiment though, for the sake of homogeneity across treatments, subjects *S* are provided with payoff tables as illustrated in Figure 1.

YOUR CONTRIBUTION

THE OTHER GROUP MEMBER'S CONTRIBUTION

Perso →		12	11	10	9	8	7	6	5	4	3	2	1	0
↓	Group → ↓	0	1	2	3	4	5	6	7	8	9	10	11	12
12	0	264 264	259 277	253 291	248 305	243 321	238 337	233 355	229 373	225 392	221 413	217 434	213 457	209 480
11	1	277 259	271 271	265 284	259 298	254 313	249 329	244 346	239 364	234 383	230 403	225 424	221 446	217 469
10	2	291 253	284 265	278 278	272 292	266 306	260 322	255 338	249 356	244 374	239 394	235 414	230 435	226 458
9	3	305 248	298 259	292 272	285 285	279 299	273 314	267 330	261 347	255 365	250 384	245 404	240 425	235 447
8	4	321 243	313 254	306 266	299 279	292 292	286 307	280 323	273 339	267 357	262 375	256 395	251 415	245 437
7	5	337 238	329 249	322 260	314 273	307 286	300 300	293 315	287 331	280 348	274 366	268 385	262 405	257 427
6	6	355 233	346 244	338 255	330 267	323 280	315 293	308 308	301 324	294 340	288 358	281 376	275 396	269 417
5	7	373 229	364 239	356 249	347 261	339 273	331 287	324 301	316 316	309 332	302 349	295 368	288 387	282 407
4	8	392 225	383 234	374 244	365 255	357 267	348 280	340 294	332 309	325 325	317 341	310 359	303 378	296 397
3	9	413 221	403 230	394 239	384 250	375 262	366 274	358 288	349 302	341 317	333 333	326 350	318 369	311 388
2	10	434 217	424 225	414 235	404 245	395 256	385 268	376 281	368 295	359 310	350 326	342 342	334 360	326 379
1	11	457 213	446 221	435 230	425 240	415 251	405 262	396 275	387 288	378 303	369 318	360 334	351 351	343 370
0	12	480 209	469 217	458 226	447 235	437 245	427 257	417 269	407 282	397 296	388 311	379 326	370 343	361 361

Figure 1: Detailed payoff table provided to participants in Treatment *S*

In all treatments, payoff tables are read as follows: the columns are for the subject's own

[14] It can be checked that a CES function with such parameters and a linear function with the same parameters are equivalent in terms of payoffs.

contribution numbers (filled in dark red) and the rows are for the co-player's contribution numbers (filled in dark blue). Red payoffs are the subject's payoffs and blue payoffs are the other group member's payoffs. Personal contributions are also displayed above the contributions possibilities in order to help subjects understand that their choice of contributions to the public good determines directly how many tokens they assign to their personal or private activity.

Treatment C underlies complementarity with $\varepsilon_1 = \varepsilon_2 = 0.7$. This treatment is homogeneous, with a non-additive functional form implying interior Nash equilibrium and social optimum. It is optimal for both subjects to contribute 3 which is a non-dominant strategy[15] in this treatment. Non-dominant strategies generally induce more variance of contributions (Sefton and Steinberg, 1996). Though, in this experiment, it is easy to find what is the dominant strategy by interval of the other's contributions. So, depending on their belief and gain of experience along the game, subjects can find an "interval-based" dominant strategy. [16]

YOUR CONTRIBUTION

THE OTHER GROUP MEMBER'S CONTRIBUTION

Perso →		12	11	10	9	8	7	6	5	4	3	2	1	0
↓	Group → ↓	0	1	2	3	4	5	6	7	8	9	10	11	12
12	0	170 / 170	186 / 187	206 / 213	222 / 241	232 / 269	236 / 297	233 / 325	226 / 353	215 / 380	201 / 406	187 / 431	175 / 456	170 / 480
11	1	187 / 186	209 / 209	228 / 234	241 / 260	248 / 285	248 / 310	243 / 334	233 / 357	219 / 380	203 / 402	188 / 424	175 / 445	170 / 465
10	2	213 / 206	234 / 228	251 / 251	260 / 273	263 / 294	260 / 315	252 / 335	239 / 355	223 / 374	205 / 393	189 / 410	175 / 428	170 / 444
9	3	241 / 222	260 / 241	273 / 260	279 / 279	278 / 297	272 / 314	260 / 330	244 / 346	226 / 362	207 / 377	189 / 391	176 / 405	170 / 419
8	4	269 / 232	285 / 248	294 / 263	297 / 278	292 / 292	283 / 306	268 / 319	250 / 332	230 / 344	209 / 356	190 / 367	176 / 378	170 / 389
7	5	297 / 236	310 / 248	315 / 260	314 / 272	306 / 283	293 / 293	276 / 303	255 / 313	233 / 322	211 / 331	191 / 340	176 / 348	170 / 356
6	6	325 / 233	334 / 243	335 / 252	330 / 260	319 / 268	303 / 276	283 / 283	260 / 290	236 / 297	212 / 303	192 / 310	176 / 316	170 / 322
5	7	353 / 226	357 / 233	355 / 239	346 / 244	332 / 250	313 / 255	290 / 260	265 / 265	239 / 270	214 / 274	192 / 278	176 / 282	170 / 286
4	8	380 / 215	380 / 219	374 / 223	362 / 226	344 / 230	322 / 233	297 / 236	270 / 239	242 / 242	216 / 245	193 / 247	176 / 250	170 / 252
3	9	406 / 201	402 / 203	393 / 205	377 / 207	356 / 209	331 / 211	303 / 212	274 / 214	245 / 216	217 / 217	193 / 218	176 / 220	170 / 221
2	10	431 / 187	424 / 188	410 / 189	391 / 189	367 / 190	340 / 191	310 / 192	278 / 192	247 / 193	218 / 193	194 / 194	177 / 194	170 / 195
1	11	456 / 175	445 / 175	428 / 175	405 / 176	378 / 176	348 / 176	316 / 176	282 / 176	250 / 176	220 / 176	194 / 177	177 / 177	170 / 177
0	12	480 / 170	465 / 170	444 / 170	419 / 170	389 / 170	356 / 170	322 / 170	286 / 170	252 / 170	221 / 170	195 / 170	177 / 170	170 / 170

Figure 2: Detailed payoff table provided to participants in Treatment C

The complementarity structure is easy to identify. Considering that the other group member contributes zero, subject C gets the lowest payoff (170) at the extreme ends of the table *i.e.* when she contributes zero and when she contributes everything. Indeed, subjects C are better off when they both enjoy the private good and the public good. If subject C contributes all her

[15]The best response depends on the contribution of the other individual in the same group.

[16]*E.g.* in Figure 2, when the other's contribution is between 3 and 4, it is better to contribute 3. When between 1 and 2, it is better to contribute 4.

endowment, then the private component of her utility is zero, which keeps her from enjoying the public good for any contribution of the other subject. Conversely, if she contributes nothing to the public good and the other member also contributes zero, she gets the lowest payoff as private benefits cannot be enjoyed without public benefits. Typically, subjects of type C are more constrained by the structure of their payoff than subjects S because they need both increases of the public good and the private good benefits to increase their payoff.

Treatment $S \times C$ and $C \times S$ depart from the two other treatments in that it is payoff-asymmetric. Subject S chooses how much to contribute according to a payoff table which reflects sub-

YOUR CONTRIBUTION

THE OTHER GROUP MEMBER'S CONTRIBUTION

Perso →		12	11	10	9	8	7	6	5	4	3	2	1	0
↓	Group → ↓	0	1	2	3	4	5	6	7	8	9	10	11	12
12	0	264 / 170	259 / 187	253 / 213	248 / 241	243 / 269	238 / 297	233 / 325	229 / 353	225 / 380	221 / 406	217 / 431	213 / 456	209 / 480
11	1	277 / 186	271 / 209	265 / 234	259 / 260	254 / 285	249 / 310	244 / 334	239 / 357	234 / 380	230 / 402	225 / 424	221 / 445	217 / 465
10	2	291 / 206	284 / 228	278 / 251	272 / 273	266 / 294	260 / 315	255 / 335	249 / 355	244 / 374	239 / 393	235 / 410	230 / 428	226 / 444
9	3	305 / 222	298 / 241	292 / 260	285 / 279	279 / 297	273 / 314	267 / 330	261 / 346	255 / 362	250 / 377	245 / 391	240 / 405	235 / 419
8	4	321 / 232	313 / 248	306 / 263	299 / 278	292 / 292	286 / 306	280 / 319	273 / 332	267 / 344	262 / 356	256 / 367	251 / 378	245 / 389
7	5	337 / 236	329 / 248	322 / 260	314 / 272	307 / 283	300 / 293	293 / 303	287 / 313	280 / 322	274 / 331	268 / 340	262 / 348	257 / 356
6	6	355 / 233	346 / 243	338 / 252	330 / 260	323 / 268	315 / 276	308 / 283	301 / 290	294 / 297	288 / 303	281 / 310	275 / 316	269 / 322
5	7	373 / 226	364 / 233	356 / 239	347 / 244	339 / 250	331 / 255	324 / 260	316 / 265	309 / 270	302 / 274	295 / 278	288 / 282	282 / 286
4	8	392 / 215	383 / 219	374 / 223	365 / 226	357 / 230	348 / 233	340 / 236	332 / 239	325 / 242	317 / 245	310 / 247	303 / 250	296 / 252
3	9	413 / 201	403 / 203	394 / 205	384 / 207	375 / 209	366 / 211	358 / 212	349 / 214	341 / 216	333 / 217	326 / 218	318 / 220	311 / 221
2	10	434 / 187	424 / 188	414 / 189	404 / 189	395 / 190	385 / 191	376 / 192	368 / 192	359 / 193	350 / 193	342 / 194	334 / 194	326 / 195
1	11	457 / 175	446 / 175	435 / 175	425 / 176	415 / 176	405 / 176	396 / 176	387 / 176	378 / 176	369 / 176	360 / 177	351 / 177	343 / 177
0	12	480 / 170	469 / 170	458 / 170	447 / 170	437 / 170	427 / 170	417 / 170	407 / 170	397 / 170	388 / 170	379 / 170	370 / 170	361 / 170

Figure 3: Detailed payoff table provided to subjects S in Treatment $S \times C$

stitutability between the private and public goods while Subject C decides according to a complementarity-payoff table. The Nash equilibrium is for subject S to contribute nothing and for subject C to supply 5. Notice that the Nash equilibrium does not change for subjects S from the homogeneous to the heterogeneous treatment because it is a dominant strategy. Though, since subjects C have a non-dominant Nash strategy, their optimal contribution from Treatment C to Treatment $S \times C$ changes.

A summary of the key experimental characteristics in each treatment is provided in Table III.[17] The constants C and η of the payoff function (see eq. (8)) are respectively set to 170 and

[17]Contributions and payoffs displayed here are rounded.

2.304.

Table III: Specifications of the experimental treatments

		Treatment S	**Treatment** C	**Treatment** $S \times C$	
		Both Subjects	*Both Subjects*	*Subject S*	*Subject C*
ε	Value	1000	0.7	1000	0.7
Nash choice	Contribution	0	3	0	5
	Payoff	264	279	337	236
Social choice	Contribution	12	5	12	0
	Payoff	361	293	209	480
Gain to cooperation	%	36.7	5.0	-38	103.4

Notice that the gain to cooperation[18] is greater in Treatment S than in Treatment C. This is intrinsic to the complementarity payoff structure. In Treatment C, since the Nash and social outcomes are interior to the choice space, the gain to cooperation (or equivalently the strength of the social dilemma) is smaller than in Treatment S where these outcomes are at opposite boundaries. Note that the gain to cooperation turns negative for subjects S in the heterogeneous treatment $S \times C$. This is because they now play with subjects for whom contributing is optimal. On the contrary, the gain to cooperation of C is very high because they now play with subjects for whom contributing nothing is optimal, which incentivizes C subject to contribute more in order to get their maximum payoff.

Thanks to the use of detailed payoff tables all along the experiment, the degree of transparency across treatments is held constant. This format of payoffs presentation is necessary in that the payoff structure is not separable. Andreoni (1993) and Cason et al. (2002) also use this format. Even in separable designs like in Bracha et al. (2011) and Yamakawa et al. (2016), payoff tables are employed for the sake of clarity and comprehensiveness. For a review on the use of payoff tables in public good games, see Saijo (2008).

3.3 Experimental design and procedures

The experiment was computerized using the software z-Tree (Fischbacher, 2007). A lab experiment was run in the University of Gothenburg with 48 students.[19] Subjects were recruited through the ORSEE procedure (Greiner, 2004).

Instructions were read aloud and the reading of the payoff table was explained on a short slide show.[20] Instructions are provided in Appendix D. Then, they followed instructions on the

[18] It is the relative difference between the Nash and the social outcomes.
[19] 4 sessions with 12 subjects each.
[20] They had 5 more minutes to review the instructions after I read it.

computer. A preliminary incentivized question to elicit attitude towards risk was first asked to subjects. I used the simple single-shot method of Gneezy and Potters (1997)[21] to achieve this. The attitude towards risk may explain the choice of individuals especially subjects C whose Nash strategy is non-dominant.[22]

During one session, half of subjects were randomly attributed a type, either type S or type C, and the other half, the remaining type. During 10 periods (first part), subjects were randomly paired with each other subject of the same type one at a time[23]. This means they were scattered in homogeneous groups. Therefore, the first part consisted at the same time of Treatment S and Treatment C (between-subject design). For another 10 periods (second part), the strangers matching design still applied but each group was composed of one subject with type S and one subject with type C, which resulted in heterogeneous groups. This constituted the $S \times C$ and $C \times S$ treatments. From the first to the second part, for every subject, only the payoffs of the other group member changed *i.e.* the red payoffs in the tables remained the same.
To control for order effects (homogeneous-heterogeneous treatments), the counterbalanced order was also run in different sessions.[24]

Thus the experiment encompassed two features: a between-subject design in the sense that subjects were attributed a type for the entire session but a within-subject design in the sense that all subjects experienced both a homogeneous treatment (either S or C depending on their type) and a heterogeneous treatment ($S \times C$ or $C \times S$ depending on their type). A global within-design is implemented because I investigate whether interacting with somebody who has different payoffs changes one's behavior. It allows for an analysis of type-specific reactions to heterogeneity in payoff structures.

Subjects were provided with two payoff tables (one compressed and one detailed[25]) labelled according to the part they were going through. Appendix C provides the compressed payoff tables. To improve clarity, their payoff was colored in red and written in bold in the tables while their co-player's payoff was in blue and not bold.[26] At each period, they had to decide how much they contribute to the group account. They were told that the tokens not contributed were automatically assigned to their personal account which only benefits them, not the other player. Also, they were asked to guess the contribution of the other group member. On the one hand, it gave insight of how to understand the table *i.e.* fixing your belief facilitates the choice

[21]Reviewed in Charness et al. (2013).

[22]Subjects C may hesitate between two strategies around the Nash strategy and choose a lower contribution if they are risk averse for example.

[23]I chose a strangers matching design following Andreoni and Croson (2008)'s recommendations: "if a prediction is based on a single-shot equilibrium, then a strangers condition will be most appropriate".

[24]Two sessions of 12 subjects each were run under the *regular* treatment described here, and another two sessions were run under the *counterbalanced* treatment.

[25]They were told that the compressed table was a reduced form of the detailed one which allowed them to get acquainted with the reading of the payoff table. 56.25% of the subjects found it useful or very useful. 27.08% found it was not useful at alland 16.67% were undecided.

[26]This is similar to Bracha et al. (2011)'s design.

of your contribution. On the other hand, subjects were encouraged[27] to pay attention to the other's contribution and/or payoff.

Before entering the paying periods, subjects answered 10 control questions to make sure they understood the task.[28] They also went through 2 practice periods to get acquainted with the presentation of payoffs.

The payoff function and tables used in the practice periods were different from the paying periods to educate them on how the table works. Five minutes were given to subjects for the reading of both their first and second parts payoff tables.

At the end of the session, two numbers were randomly drawn so as to determine subjects' real earnings: one period from part 1 and one period from part 2. The earnings from the experiment were the average payoff from these two periods.[29] The average payoff was 210 SEK.

3.4 Predictions

Standard predictions are based on theoretical ground. Behavioral conjectures go beyond the theoretical predictions to identify behavior motives in each treatment.

3.4.1 *Standard predictions*

Since the Nash strategy changes from one treatment to the other, I cannot compare directly the levels of contributions. As a variable of comparison, I use the difference between the Nash equilibrium and experimental observations relatively to the distance between the maximum possible contribution (endowment w) and the Nash contribution. In other words, the deviation to the Nash is normalized by the decision space over Nash,[30] so that overcontributions relative to the Nash are compared across treatments. The rate of overcontribution is defined as in Willinger and Ziegelmeyer (2001):

$$d^* = \frac{y_i - y_i^*}{w - y_i^*} \tag{13}$$

In addition to being able to compare all treatments, it allows me to determine whether the overcontribution pattern observed in the linear public good game (S) extends to Treatment C, which is the first research question. Put differently, do subjects tend to overcontribute whatever the structure of their payoffs?

[27]They earned an additional amount (20 EMUs, see Instructions in Appendix D) if they guess exactly. This is a small amount because I do not want them to focus too much on this task compared to the contribution task. For a comprehensive review on belief elicitation, see Schotter and Trevino (2014).

[28]These questions allowed me to evaluate their understanding of the task.

[29]I chose to pick two random numbers instead of usually one to avoid large differences between subjects C's payoffs and subjects S's payoffs. Indeed, subjects S are more likely to earn less in the homogeneous treatment than the heterogeneous relatively to subjects C. Conversely subjects C earn relatively less than subjects S in the heterogeneous treatment.

[30]Over (and not under) Nash because the Nash strategy of subjects S is zero so they can only overcontribute.

A strict application of the theory to every treatment leads to Hypothesis 1.

Hypothesis 1 (Pure self-interest) *The rate of overcontribution is zero for all treatments.*

In other words, subjects play the Nash strategy in all treatments. However, strictly positive overcontributions are often noticed in linear experiments like Treatment S (Ostrom, 2000) and persist in nonlinear experiments. In the latters, overcontributions are found smaller as the Nash equilibrium increases (Willinger and Ziegelmeyer, 2001) and even turn negative when the level is high (Isaac and Walker, 1998). Overcontributions are generally interpreted as a natural tendency to cooperation.

Hypothesis 2 (Invariant rate of overcontribution) *For subjects S, the rate of overcontribution remains the same in homogeneous and heterogeneous groups.*

Since subjects S's Nash strategy is the same across the homogeneous and heterogeneous treatments, there is no theoretical reason for a change of their rate of overcontribution.

3.4.2 *Behavioral conjectures*

I expect less overcontributions in Treatment C because the Nash equilibrium is interior. This is a classical prediction when studying nonlinear games.

Conjecture 1 (Overcontribution differences) *Subjects C overcontribute less than subjects S in homogeneous groups.*

As Vesterlund (2016) put forward, one reason for the introduction of interior Nash equilibrium (thus nonlinear games) in the literature was to check whether it corresponded more to the observed pattern in linear public good games (non-zero contributions). For example, with a Nash contribution of 8 (out of 24), Cason et al. (2002) find no significant differences between observed contributions and the Nash contribution, for American subjects. They used a highly nonlinear (Cobb-Douglas) function.

The rest of this subsection relies on the second research question of the paper namely, whether interacting with a different type of individual changes one's behavior motives. Indeed, while the previous subsection is based upon theory, it is worthwhile raising other concerns which may motivate subjects' decisions. Subjects come to the lab with their own preferences which may affect their behavior.

Conjecture 2 (Free-riding) *Subjects S contribute zero more often in the heterogeneous treatment than in the homogeneous treatment.*

For subjects S, playing with subjects C whose optimal decision is to contribute 5 strengthens their incentive to free ride compared with playing with their peers. This outcome is likely to arise during the last periods of the heterogeneous treatment since subjects may need to learn the other group member's strategy.[31]

Conjecture 3 (Social optimum) *Contributions of subjects C reflect the social optimum in the homogeneous treatment.*

It is easy to identify the social optimal outcome in Treatment C because it is close to the Nash.[32] Thus, I expect subjects C to contribute the social optimal amount of tokens rather than the Nash amount. Due to learning effects, this might be observed only for the last periods of the homogeneous treatment.

When comparing S's payoffs with C's payoffs (see Figure 3 for such a comparison), it can be noticed that subjects C basically earn less than subjects S.[33] This may lead to inequality aversion for both subjects. It is then worthwhile studying how much subjects S dislike being in the head of subjects C and conversely, how much subjects C suffer from being behind subjects S. For this purpose and based on Fehr and Schmidt (1999), I define respectively the advantageous and the disadvantageous inequalities as follows:

$$\varphi^{+} = \max(0, \pi_{\mathrm{i}} - \pi_{-\mathrm{i}}) \tag{14}$$

$$\varphi^{-} = \max(0, \pi_{-\mathrm{i}} - \pi_{\mathrm{i}}) \tag{15}$$

with π_i the subject's profit and π_{-i} her group member's profit.

Conjecture 4 (Advantageous inequality) *Advantageous inequality increases the rate of overcontribution of subjects S in heterogeneous groups.*

In the case of inequality aversion, S can reduce the gap between her payoff and C's payoff by contributing more for a given strategy of C (refer to Figure 3).

Conjecture 5 (Disadvantageous inequality) *Disadvantageous inequality decreases the rate of overcontribution of subjects C in heterogeneous groups.*

If subjects C are inequality averse, their only strategy to protest against inequality is to reduce their contribution in order to reduce subjects S's payoff. Therefore, they may contribute less

[31] Note that Conjecture 2 can either be tested with the contribution variable or the overcontribution variable since contributing zero is optimal for subjects S across both the homogeneous and the heterogeneous treatments.

[32] This is the maximum payoff on the diagonal of the table, see Figure 2.

[33] This is only due to the substitutability versus complementarity structure of the payoff since the monotonic transformation of the CES utility function into the payoff function is the same for both types. Indeed, the complementarity structure constrains subjects C more than subjects S are constrained by their linear structure which reflects a perfect substitutability between the personal and group benefits.

than the Nash strategy. However, this implies that they would be willing to sacrifice their profit as well. This type of inequality effect may be regarded as spitefulness in the case of subjects C.

I expect these conjectures to be sensitive to order effects. Whether subjects start with the homogeneous or heterogeneous treatment may lead to different behavior. Indeed, dealing in the first part with an asymmetric payoff table is harder than with a symmetric payoff table.

Finally, since beliefs are elicited and incentivized, it is worthwhile studying the stability of beliefs: since the strategy is nondominant in Treatment C, are beliefs more stable in Treatment S where the Nash equilibrium is identifiable? Then, do beliefs become more stable when subjects C enter Treatment $C \times S$ where it is easier to determine the (dominant) strategy of subject S? Do we observe the reverse for subjects S who may be confused when evaluating the payoffs of their group member of type C (because of the nondominant strategy)? Beliefs are a good indicator for the understanding and learning of subjects, thus can inform whether a conjecture is robust or not.

4 Preliminary results

My experiment is designed to examine *(i)* whether overcontributions persist under a structure of payoffs which reflects complementarity between private and public goods, which is more in line with empirical evidence, and *(ii)* how the introduction of the heterogeneity of payoff structures within groups changes behavior. In this section, I first analyze the effect of treatments on overcontributions. Then, I explore potential determinants of behavior under each type of payoff structure in both homogeneous and heterogeneous groups with the help of panel-data econometric methods.

4.1 Visual inspection

Table IV displays the average contributions of both types for both treatments (homogeneous or heterogeneous) and for the regular vs. the counterbalanced order. In the regular order, subjects first played in homogeneous groups, then in heterogeneous groups. In the counterbalanced order, subjects first played in heterogeneous groups then in homogeneous groups.

Regarding the regular order, Subjects S tend to contribute less when they play with a different type of subject (2.20) than when they play with their peers (4.42). On the contrary, subjects C tend to contribute more when they play with subjects S (3.87) than when they play with their peers (3.66). The standard deviation is lower for subjects C than subjects S. This may be due to the greater social dilemma underlied in the perfect substitutability structure. Some subjects may be more cooperative than others. By contrast, there is less social dilemma in the complementarity structure as put forward in Table III.

Regarding the counterbalanced order, the same is noticed even though more slighly.

Table IV: Average contributions by type and treatment

	Average contributions					
	All treatments		***Regular order***		***Counterbalanced order***	
	Homog	Heterog	Homog (1)	Heterog (2)	Homog (2)	Heterog (1)
Type *S*	3.62 (0.26)	2.38 (0.20)	4.42 (0.38)	2.20 (0.32)	2.82 (0.34)	2.57 (0.24)
Type *C*	3.33 (0.11)	3.58 (0.14)	3.66 (0.17)	3.87 (0.17)	2.99 (0.15)	3.29 (0.23)

* The numbers in parenthesis next to "homogeneous" or "heterogeneous" indicate the part in which the treatment was run. For example, homogeneous (2) means that subjects played in homogeneous groups during the second part of the session.
* The numbers in parenthesis inside the table are the standard errors.

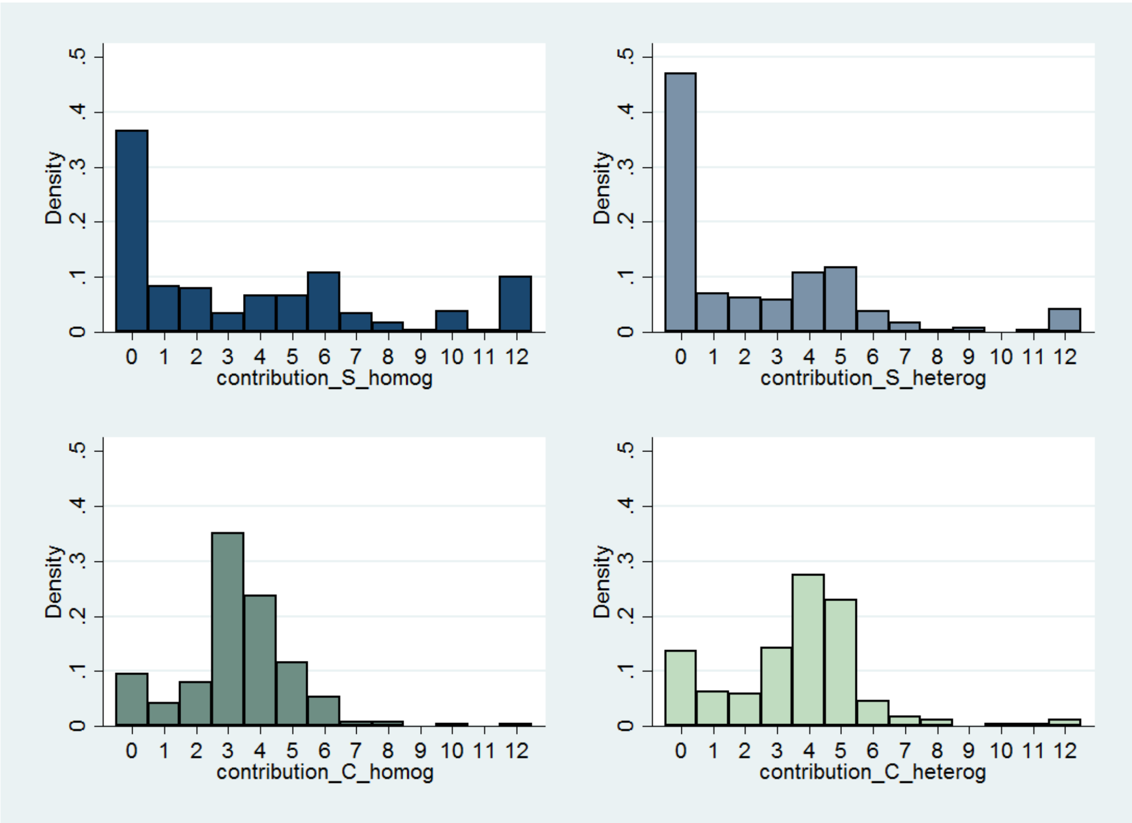


Figure 4: Fraction of subjects for each contribution by treatment

Figure 4 displays the fraction of each contribution in the different treatments. The two blue charts (at the top) represent subjects *S* densities of contributions and the two green charts (at the bottom) represent subjects *C* densities of contributions. The distributions of contributions are clearly different between the two types of subjects. Particularly, the complementarity pattern is well-illustrated by the major number of contributions inside the choice space. The perfect substitutability pattern specific to the linear (additive) game stands out as well through the large number of zero contributions.

In homogeneous groups, 36.67% of subjects *S* contributed zero which is the Nash strategy.

Still, many subjects tended to cooperate. On average subjects *S* contributed 29% of their endowment, which is a bit lower than what is found in the literature on linear public good games (between 40 and 60%). This may be due to the payoff table format which is easier to understand than the sole usually given payoff function. Zero contributions increase from the homogeneous (36.67%) to the heterogeneous treatment (47.08%). This goes along the lines of Conjecture 2.

Subjects *C* mostly contributed 3 (35.00%) or 4 (23.75%) in the homogeneous treatment and 4 (27.50%) or 5 (22.92%) in the heterogeneous treatment. Note that a contribution of 4 from both players is as well associated with an egalitarian outcome in every treatment. Subjects both receive 292 (see Figures 1, 2 and 3), which may be a motive for egalitarian subjects.

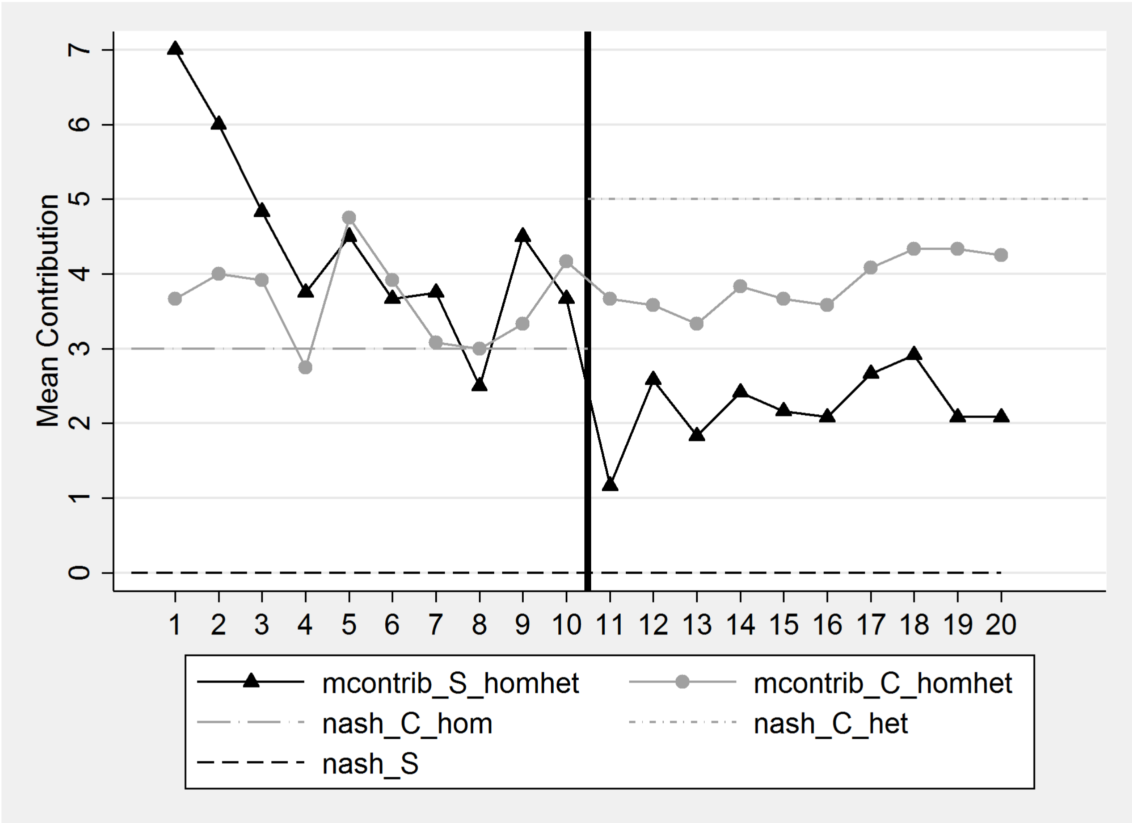


Figure 5: Mean contributions over periods

Figure 5 shows mean contributions over time for the regular order in which subjects first interacted in homogeneous groups then in heterogeneous groups.[34] While this is difficult to disentangle subjects *S* and *C* in Part 1 where they play with their peers, there is a clear distinction in the heterogeneous treatment. In the homogeneous part (from period 1 to period 10), subjects *C* contribute positive amounts of tokens which is contrary to their self-interested contribution of zero. Thus they tend to cooperate. As in the literature, there is a globally decreasing amount of contributions over periods mainly due to a learning effect. When entering the heterogeneous treatment, contributions of subjects *S* drastically fall compared with those of subjects *C*. This

[34]The counterbalanced order results are in Appendix E and discussed in subsection 4.2.3 which deals with order effects. In summary, due to a design problem, the graph of mean contributions for the counterbalanced order (Figure 12) is not suitable for interpretation.

is due to the fact that subjects *S* now play with subjects *C* for whom it is optimal to contribute. It looks like free-riding strongly operates in the heterogeneous part as Conjecture 2 predicts.

For subjects *C*, there seems to be a few differences in contributions between the homogeneous and the heterogeneous treatments. The contributions look more stable than subjects *S*'s contributions. This can be explained by the weaker social dilemma they experience compared with subjects *S*. Contributions seem less variable in the heterogeneous treatment. This could be due to the learning effect. Another potential reason would be that it is easier to identify subjects *S*'s strategy since it is dominant compared to subjects *C*. This leads subjects *C* to keep contributing rather high amounts of tokens in the heterogeneous treatment as the other player (subject *S*) contributes globally less than them.

4.2 Structure of payoffs and treatment effects

To be able to compare treatments, the variable of interest is the rate of overcontribution compared to the Nash rather than the contribution, as explained in subsection3.4. The first subsection analyzes the effect of the type of payoff structure (either perfect substitutability or complementarity) on overcontributions, so this is a between-subject analysis. The second subsection examines the effect of the treatment (homogeneous versus heterogeneous groups) on overcontributions within types. The third subsection offers a preliminary analysis of order effects, *i.e.* whether first playing in homogeneous then in heterogeneous groups or the reverse affects the results.

4.2.1 *Structure of payoffs and type*

The first research question deals with whether complementarity between private and public goods reduces the rate of overcontribution compared with perfect substitutability.

Table V displays the mean overcontribution of subjects *S* and subjects *C* in each of the treatments, homogeneous and heterogeneous. Hypothesis 1 (whether the overcontribution rate is zero) is first tested for each treatment and each subject type. Since non-parametric tests are not fitted to test such a hypothesis, a bootstrap is first operated in order to ensure the normal distribution of overcontributions so as to perform a (parametric) t test.

Result 1 *Subjects in general are not purely self-interested individuals whether they interact with the same or a different type of subject.*

As displayed in Table V, the null hypothesis is rejected at the 1% level for each treatment and each subject type.

Then, a (non-parametric) Mann Whitney test is run in order to test for the equality of mean overcontributions across subject types. Does the structure of payoffs affect the rate of overcontribution? Do overcontributions persist under the complementarity structure? The Mann

Table V: Average overcontributions by type and treatment

		homogeneous	heterogeneous
S	Overcontribution (std. err.)	30% (0.02)	20% (0.02)
	Bootstrap t test	**16.85**	**16.12**
	***p*-value**	***0.0000***	***0.0000***
C	Overcontribution (std. err.)	4% (0.01)	−20% (0.02)
	Bootstrap t test	**2.89**	**-7.55**
	***p*-value**	***0.004***	***0.0000***
	Mann Whitney test	**8.353**	**14.712**
	***p*-value**	***0.0000***	***0.0000***

[a] The null hypothesis of the bootstrap t test is that overcontributions are equal to zero (refer to Hypothesis 1).
[b] The null hypothesis of the Mann Whitney test is that overcontributions for subjects *S* and subjects *C* are equal (refer to Conjecture 1).

Whitney test rejects the null hypothesis of equal means at the 1% level, resulting in a lower level of overcontributions for subjects *C* than subjects *S*, as expected in Conjecture 1.

Result 2 *The structure of payoffs affects the rate of overcontribution.*

Result 3 *In homogeneous groups, subjects overcontribute less under a structure of complementarity than under a structure of perfect substitutability.*

Result 3 is in line with the literature on interior Nash equilibrium. The higher the Nash equilibrium, the lower the rate of overcontribution, except for very high levels of the equilibrium (Willinger and Ziegelmeyer, 2001).

In the heterogeneous treatment, the rate of overcontribution of subjects *C* turns negative, which means that they undercontribute. This may be explained by an aversion to inequality. Subjects *C* should theoretically contribute more (5) in the heterogeneous treatment than in the homogeneous treatment (3) while subjects *S* should contribute zero. Given the higher Nash outcome of subjects *S* (337) than subjects *C* (236), subjects *C* may want to penalize subjects *S*. The inequality aversion conjecture will be tested in subsection 4.2.2. Another potential explanation is that subjects *C* expect a positive contribution from subjects *S*. Since subjects *C*'s strategy is non-dominant, the more subjects *S* contribute, the less subjects *C* should contribute if they want to maximize their outcome. In this respect, it is interesting to test whether overcontributions of subjects *C* increase across periods in the heterogeneous treatment, as they learn across periods the strategy of their co-player. For the latter potential explanation, a (non-parametric) paired-sample sign test is run to examine whether the overcontributions in the first five periods of the heterogeneous treatment are equal to the overcontributions in the five last periods. There is however no significant difference between the first and last five periods (two-sided *p*-value =

0.9170).

Finally, Conjecture 3 is rejected by a bootstrapped t test ($z = -8.49$, p-value=0.000). This means that even though the social optimum is easily identifiable for subjects C in homogeneous groups, this is not the main strategy employed.

4.2.2 *Structure of payoffs and heterogeneity*

The second research question deals with the effect of within-groups heterogeneous payoff structures on the rate of overcontribution. For this purpose a paired-sample sign test[35] is performed in order to compare each type of subjects across the homogeneous and the heterogeneous treatments.

Table VI: Average overcontributions by type and treatment

		Average rates of overcontribution		
Type	Treatment	First 5 periods	Last 5 periods	All periods
S	homogeneous	36% (0.03)	24% (0.03)	30% (0.02)
	heterogeneous	20% (0.02)	19% (0.02)	20% (0.02)
	Sign test *p* value	**0.0015**	**0.7239**	**0.0076**
C	homogeneous	3% (0.02)	4% (0.02)	4% (0.01)
	heterogeneous	−19% (0.03)	−22% (0.03)	−20% (0.02)
	Sign test *p* value	**0.0000**	**0.0000**	**0.0000**

[a] Numbers in parenthesis are the standard errors of the mean of overcontributions.
[b] The null hypothesis of the sign test is that the mean of overcontribution when subjects play in homogeneous groups is equal to the mean of overcontributions in heterogeneous groups (refer to Conjecture 2).
[c] The sign test p-values come from the two-sided test. The one-sided p-values are exactly half of the two-sided p-values (Moffatt, 2015).

Table VI shows the rate of overcontribution for the two types and the two treatments, and across all periods, the first five periods and the last five periods. Roughly, one can notice that overcontributions are reduced in the heterogeneous treatment compared to the homogeneous treatment for both types S and C. There is strong evidence that the rate of overcontribution is different under the heterogeneous treatment for both subjects across all periods. Note however that the evidence is mixed for subjects S as regards the last five periods.[36] Subsection 4.2.3 explains this different result by an order effect.

Result 4 *Whether subjects interact with the same or a different type of subject affects the rate of overcontribution.*

[35] A Wilcoxon signed ranks test results in the same conclusions. However the paired-sample sign test has been preferred here because the signed ranks test is not completely distribution-free (Moffatt, 2015, p.84).

[36] The comparison of the last five periods of the homogeneous and heterogeneous treatments does not result in a significant difference between the two treatments for subjects S.

Another interesting information in this table is the comparison of overcontributions as periods pass. In the homogeneous treatment, overcontributions seem to globally decrease across periods for subjects *S* (from 36 to 24%) whereas overcontributions very slightly increase for subjects *C* (from 3 to 4%). In the heterogeneous treatment, overcontributions very slighly decrease over periods for both subjects. The only significant result is the decrease of overcontributions in the homogeneous treatment for subjects *S*.[37] There are however better ways of testing whether overcontributions increase across periods than a sign test on the first half and the last half of the total periods which is a rather rough method. A dynamic panel model may be appropriate for future investigation.

4.2.3 *Structure of payoffs and order effects*

A within-subject design may result in different conclusions whether subjects go through one treatment first or the other. This subsection investigates whether there is an order effect on the results previously drawn regarding the effect of type and the effect of the treatment (homogeneous *vs.* heterogeneous) on the rate of overcontribution.

Type: Tables VII and VIII show the rate of overcontributions across type and treatment for respectively the regular and the counterbalanced orders.

Table VII: Average overcontributions by type and treatment in the regular order

		homogeneous	heterogeneous
S	Overcontribution (std. err.)	37% (0.03)	18% (0.02)
	Bootstrap t test	**12.00**	**10.96**
	***p*-value**	***0.0000***	***0.0000***
C	Overcontribution (std. err.)	7% (0.02)	−16% (0.02)
	Bootstrap t test	**4.12**	**-5.30**
	***p*-value**	***0.000***	***0.0000***
	Mann Whitney test	**6.337**	**10.354**
	***p*-value**	***0.0000***	***0.0000***

[a] The null hypothesis of the bootstrap t test is that overcontributions are equal to zero (refer to Hypothesis 1).
[b] The null hypothesis of the Mann Whitney test is that overcontributions for subjects *S* and subjects *C* are equal (refer to Conjecture 1).

There is no order effect on Results 2 and 3 (see Mann-Whitney tests in Tables VII and VIII), which confirms that the structure of payoffs affects the rate of overcontribution, and particularly that subjects *C* overcontribute less than subjects *C* in the homogeneous treatment. However, Result 1 is impacted by the order effect. In the counterbalanced order, subjects *C* contribute as the theory predicts when they interact with their peers. As the homogeneous

[37] A sign test was performed and resulted in a *p*-value of 0.0000.

Table VIII: Average overcontributions by type and treatment in the counterbalanced order

		homogeneous	heterogeneous
S	Overcontribution (std. err.)	23% (0.03)	21% (0.02)
	Bootstrap t test	**10.72**	**10.52**
	***p*-value**	***0.0000***	***0.0000***
C	Overcontribution (std. err.)	−0% (0.02)	−24% (0.03)
	Bootstrap t test	**-0.05**	**-5.03**
	***p*-value**	***0.957***	***0.0000***
	Mann Whitney test	**5.796**	**10.485**
	***p*-value**	***0.0000***	***0.0000***

[a] The null hypothesis of the bootstrap t test is that overcontributions are equal to zero (refer to Hypothesis 1).
[b] The null hypothesis of the Mann Whitney test is that overcontributions for subjects *S* and subjects *C* are equal (refer to Conjecture 1).

treatment is run after the heterogeneous treatment, subjects had time to learn across periods, whereas in the regular order, subjects first play in homogeneous groups thus gain experience on this treatment. This learning effect explains the lower overcontributions in the counterbalanced order (−0%) compared with the regular order (7%).

Treatment: Tables IX and X show the rate of overcontributions across type and treatment for respectively the regular and the counterbalanced orders across the first five periods, the last five periods and all periods.

Table IX: Average overcontributions by type and treatment in the regular order

		Average rates of overcontribution		
Type	Treatment	First 5 periods	Last 5 periods	All periods
S	homogeneous	43% (0.04)	30% (0.05)	37% (0.03)
	heterogeneous	17% (0.03)	20% (0.04)	18% (0.03)
	Sign test *p* value	**0.0000**	**0.0410**	**0.0000**
C	homogeneous	9% (0.03)	6% (0.02)	7% (0.02)
	heterogeneous	−20% (0.04)	−13% (0.03)	−16% (0.02)
	Sign test *p* value	**0.0000**	**0.0000**	**0.0000**

Contrary to the general results presented in Table VI, the effect of the treatment (homogeneous *vs.* heterogeneous) is significant for the last five periods for subjects *S* as well in the regular order. Playing in heterogeneous groups reduces the overcontributions in every case as for the general results.

However, in the counterbalanced order, during the last five periods, subjects *S* overcon-

Table X: Average overcontributions by type and treatment in the counterbalanced order

		Average rates of overcontribution		
Type	Treatment	First 5 periods	Last 5 periods	All periods
S	homogeneous	29% (0.04)	18% (0.04)	23% (0.03)
	heterogeneous	24% (0.03)	19% (0.03)	21% (0.02)
	Sign test p value	**0.7608**	**0.1877**	**0.2185**
C	homogeneous	−2% (0.03)	2% (0.02)	0% (0.02)
	heterogeneous	−17% (0.05)	−31% (0.04)	−24% (0.03)
	Sign test p value	**0.0000**	**0.0000**	**0.0000**

tribute slightly more in the heterogeneous treatment, which is at odds with the previous conclusions. Though, this result is not significant, which explains the non-significant test result in the aggregation of the regular and the counterbalanced orders (see Table VI). Result 4 does not hold for subjects S.

Thus, there is an order effect on the results. This is also noticed across periods in Appendix E. This seems to be attributed to confusion of subjects in the counterbalanced order. One explanation is the use of a symmetric (homogeneous) payoff table for the control questions and the two practice periods in both the regular and the counterbalanced orders. This means that subjects in the counterbalanced order trained on a homogeneous treatment while they started the paying periods in heterogeneous groups. This may have confused them during the first periods of the game *i.e.* during the heterogeneous treatment. The learning effect may have a role as well. A decrease in contributions is often observed and attributed to a learning effect in repeated public good games. Therefore, whether one starts in homogeneous groups or heterogeneous groups may be affected by this learning effect. For future research, confusion could be studied in order to disentangle it from any other treatment effect, order effect or learning effect.

4.3 An exploration of behavioral determinants

This subsection is a preliminary analysis of behavior motives. First, free-riding outcomes are studied across treatments. Second, inequality aversion is explored.

4.3.1 *Free-riding*

In this subsection, the number of free-riding outcomes is compared across treatments. Figure 6 shows the proportion of free-riding outcomes by type in both homogeneous and heterogeneous groups.

The first thing to note is that the proportion of free-riding outcomes is much larger among subjects S than subjects C. This is due to the two different structures of payoffs, perfect substi-

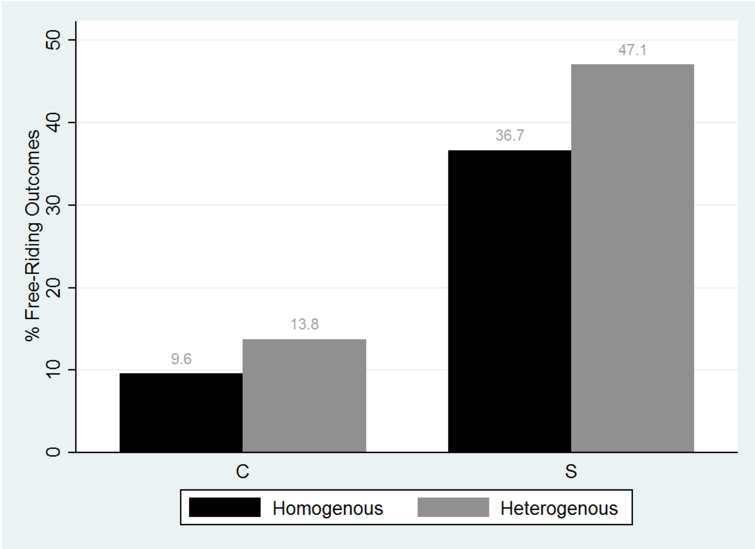


Figure 6: Percentage of free-riding outcomes by type

tutability underlying an incentive to free-ride and complementarity underlying an incentive to contribute positive amounts. A Mann-Whitney test confirms this pattern ($z = 10.564$, p-value = 0.0000).[38]

Result 5 *Free-riding occurs more often under a perfect substitutability structure than under a complementarity structure of payoffs.*

Regarding subjects S, free-riding is likely to occur more often in the heterogeneous than the homogeneous treatment as Conjecture 2 predicts. This is what the bar chart confirms: 47.1% zero contributions are reported in heterogeneous groups while only 36.7% are observed in homogeneous groups. The sign test provides strong evidence (two-sided p-value = 0.0066) that the percentage of free-riding outcomes is higher in the heterogeneous treatment than in the homogeneous treatment, which is in line with Conjecture 2.

Result 6 *Under perfect substitutability, free-riding occurs more often in heterogeneous groups than in homogeneous groups.*

Subjects S have a strong incentive to free-ride when they interact with subjects C for whom it is optimal to contribute positive amounts. Note that this is in line with the -38% gain to cooperation reported in Table III which reflects the absence of social dilemma for subjects S in heterogeneous groups.

While subjects C have no incentive to free-ride, some of them seem to rely on a positive contribution from their group member: 9.6% in the homogeneous treatment and 13.8% in the heterogeneous treatment. Free-riding is thus higher in the heterogeneous treatment as for subjects S, but this is not significant (two-sided sign test p-value = 0.2026).

[38]The same test has been perform separately for homogeneous groups ($z = 7.029$, p-value =0.0000) and heterogeneous groups ($z = 7.929$, p-value = 0.0000).

Interestingly, the heterogeneous treatment may constitute an identification method of free-riders. For future research, a typology of subjects could be worthwhile to draw from the results. Indeed, if subjects S do not contribute zero in such a setting where there is no gain to cooperation, their behavior motives may rely on other-regarding preferences such as kindness, (advantageous) inequality aversion or altruism.

4.3.2 *Inequality aversion*

In this subsection, I use a panel data framework. One advantage is that many determinants of behavior can be investigated simultaneously. Another advantage lies in the explicit recognition that n (here 48) subjects are observed making a decision in each of the T (here 20) periods. Using panel-data modeling, I propose the following general framework to test, in particular, for the influence of advantageous and disadvantageous inequalities on the rate of overcontribution:[39]

$$overcontrib_{it} = \mathrm{x}'_{it}\beta \; + z'_{i,t}\alpha + \epsilon_{it}, \quad i = 1,...,48, \quad t = 1,...,20 \tag{16}$$

$overcontrib_{it}$ is the dependent variable *i.e.* the rate of overcontribution of subject i at period t with $i = 1,...,48$ and $t = 1,...,20$. The vector x'_{it} is the vector of explanatory variables as summarized in Table XI. ϵ_{it} is the composite error term (with an assumed mean zero and variance σ^2_ϵ).

There are K regressors in $x_{i,t}$, not including a constant term. $z'_{i,t}$ is the heterogeneity, or equivalently, the individual effect. z_i contains a constant term and a set of subject-specific variables which may be observed or unobserved, all of which are taken to be constant over periods. Eq. (16) is a classical regression model: if z_i is observed for all individuals, then the entire model can be treated as an ordinary linear model and fit by least squares. Basically, three kinds of estimators may be used to estimate eq. (16) , depending on the way the individual effect $z_{i,t}$ is specified.

If z_i is supposed to only contain a constant term, then ordinary least squares provides consistent and efficient estimates of the common α and the slope vector β. Eq. (16) then becomes:

$$overcontrib_{it} = \mathrm{x}'_{it}\beta \; + \; \alpha + \epsilon_{it} \tag{17}$$

Eq. (17) corresponds to the pooled regression model.

If z_i is unobserved, but correlated with x_{it}, then the least squares estimator of β is biased and inconsistent as a consequence of an omitted variable. In this instance, eq. (16) becomes:

$$overcontrib_{it} = \mathrm{x}'_{it}\beta \; + \; \alpha_i + \epsilon_{it} \tag{18}$$

where $\alpha_i = z'_{i,t}\alpha$ embodies all the observable effects and specifies an estimable conditional

[39] Note that the following notations are independent of those in subsection 3.1.

mean. Eq. (18) corresponds to the fixed effects (FE) model. This FE approach takes α_i to be a subject-specific constant term in the regression model. The term fixed is used here to indicate that the term does not vary over time. The FE estimator is essentially a linear regression which includes a set of $n-1$ dummy variables, one for each subject in the data set (one is excluded to avoid the dummy variable trap). The presence of such dummies has the consequence that the intercept is estimated separately for each subject.

Finally, the unobserved individual heterogeneity, however formulated, may be assumed to be uncorrelated with the included variables. Then eq. (16) may be formulated as follow:

$$overcontrib_{it} = \mathrm{x}'_{it}\beta \ + \ \alpha \ + u_i + \ \epsilon_{it} \tag{19}$$

Eq. (19) corresponds to the random effects (RE) model where u_i is a subject-specific random element, similar to ϵ_{it}, except that for each subject, there is but a single draw that enters the regression identically in each period. The RE model does not estimate the intercept of each subject. It merely recognizes that they are all different, and sets out to estimate only their variance σ_u^2 (Moffatt, 2015).[40]

Table XI: Description of explanatory variables

Variable name	Description	Mean	Std Dev	Min	Max
heterogeneous	1 if heterogeneous groups	0.5	0.5002	-	-
l_mbovercontrib	Past group member's overcontribution	0.0842	.3428	-.7143	1
l_profit	Past profit	237.0821	62.6720	170	480
l_freeriding	1 if past contribution = 0	.2632	0.4406	-	-
l_adv_ineq	Past advantageous inequality	17.6552	44.1131	0	309.9828
l_disadv_ineq	Past disadvantageous inequality	59.8354	68.7481	0	309.9986
expprofit	Anticipated profit	285.9425	49.8608	170	480
exp_adv_ineq	Anticipated advantageous inequality	28.6479	54.6710	0	309.9828
exp_disadv_ineq	Anticipated disadvantageous inequality	20.8991	50.9428	0	309.9828

[a] The "l_" prefix indicates a lagged variable. This type of variable allows for an analysis of subjects' gain of experience *i.e.* potential learning effects. Even though the experiment relies on a strangers matching, subjects gain knowledge on the average strategy of their group members over periods.
[b] The "exp_" prefix (like expected) indicates subjects' belief or guess of the results of a period.

A general model including all types and treatments is first analyzed. Nonetheless, based on the evidence from the non-parametric tests run in subsection 4.2, it is worthwhile distinguishing the four following subsamples in order to disentangle behavior motives in each group.

- subjects S in homogeneous groups
- subjects S in heterogeneous groups
- subjects C in homogeneous groups
- subjects C in heterogeneous groups

[40]For the sake of comparison between the FE and the RE models, note that in the FE model, the intercept for subject i would be $\alpha + u_i$, $i = \{1,...,n\}$ *i.e.* each subject i has its own intercept.

In this paper, the relationship between the rate of overcontribution and its main determinants, as specified in eq. (16) is estimated with a FE model for all models *i.e.* the general model on the whole sample and the models on the four subsamples. The choice of a FE model is based upon the Hausman test.[41]

Table XII shows the results of the FE model for the whole sample (Model 1) and the four subsamples (Models (2) to (5)). All these models are reduced models.[42] The general results (from both the RE and the FE models) are in Appendix F.1 for the sake of robustness.

Regarding the general model (Model (1)), the within-treatment variable (*heterogeneous*) *i.e.* whether subjects are interacting in homogeneous or heterogeneous groups, is significant at the 1% level. Whatever the type of subject, interacting in heterogeneous groups reduces the rate of overcontribution compared with interacting in homogeneous groups. This is in line with the results from subsection 4.2. The anticipated profit (*expprofit*) increases the rate of overcontribution (significant at the 1% level), which is intuitive: subjects contribute relatively to what they expect to earn. The anticipated advantageous inequality (*exp_adv_ineq*) decreases the rate of overcontribution (significant at the 1% level), which demonstrates a tendency to free-ride. Conversely, the anticipated disadvantageous inequality influences positively the rate of overcontribution (significant at the 1% level). The less subjects earn relatively to their group member, the more they contribute. This could be interpreted as a hedging effect or a tendency to cooperate depending on the type of subjects. This will be further interpreted in the between-subject analysis below. Indeed, the general model does not say much about the differences across types and treatments regarding some variables. It only provides the influence of each variable in the aggregate, hence the decomposition into subsamples. Refer to Appendix F.2 for an analysis of the effect of crossed variables (type, treatment) in the general model.

Within-subject analysis: Models (2) and (3) are compared within type *S* and Models (4) and (5) are compared within type *C*. The past other member's overcontribution (*l_mbovercontrib*) is significant at the 1% level in both Models (2) and (3). Interestingly, in homogeneous groups, the past other member's overcontribution influences positively the rate of overcontribution whereas in heterogeneous groups, the effect is negative. This illustrates the tendency to co-operation when subjects *S* play with their peers: if subjects tend to cooperate, this catalyzes positive contributions. However, there is no incentive to cooperate in heterogeneous groups: the more subjects *C* overcontribute, the less subjects *S* have an interest in overcontributing. The past profit (*l_profit*) is significant at the 10% level in Model (2) and at the 5% level in Model (3). The effect has different signs in homogeneous to heterogeneous groups within subjects *S* population. This further supports the previous conclusion. In homogeneous groups, the more subjects *S* earn in the past period (which is directly linked to their group member's contribu-

[41]This choice further justifies the subdivision of the sample into four subsamples since the between-treatment variable *i.e.* the type of subject is a time-invariant dummy variable which cannot be identified by the FE model.

[42]The variables which were not significant at the 10% level were dropped.

Table XII: Fixed effects model results

	General	SUBJECTS S		SUBJECTS C	
		homogeneous	heterogeneous	homogeneous	heterogeneous
	Model (**1**)	Model (**2**)	Model (**3**)	Model (**4**)	Model (**5**)
	Overcontribution	Overcontribution	Overcontribution	Overcontribution	Overcontribution
heterogeneous	-0.1207***				
	(0.0232)				
l_mbovercontrib	-0.0538***	0.0244***	-0.0138***		
	(0.0169)	(0.0086)	(0.0060)		
l_profit		0.0002*	-0.0002**		
		(0.0001)	(0.0001)		
l_freeriding		0.0117*			0.1170**
		(0.0067)			(0.0506)
l_adv_ineq		-0.0002**	0.0003**		
		(0.0001)	(0.0001)		
l_disadv_ineq		0.0001***			0.0007*
		(0.0001)			(0.0004)
expprofit	0.0060***	0.0104***	0.0113***	0.0033***	0.0040***
	(0.0007)	(0.0002)	(0.0003)	(0.0011)	(0.0005)
exp_adv_ineq	-0.0057***	-0.0081***	-0.0085***	-0.0042***	-0.0044***
	(0.0005)	(0.0001)	(0.0002)	(0.0006)	(0.0010)
exp_disadv_ineq	0.0051***	0.0061***	0.0064***	0.0048***	0.0060***
	(0.0003)	(0.0001)	(0.0002)	(0.0004)	(0.0004)
constant	-1.5145***	-2.7747***	-2.9219***	-0.8672***	-1.3810***
	(0.2254)	(0.0621)	(0.0727)	(0.3091)	(0.1115)
Nb obs	912	228	228	240	228
Nb groups	48	24	24	24	24
R^2_adj	0.6900	0.9853	0.9879	0.6043	0.6557
FE cluster	*subject*	*subject*	*subject*	*subject*	*subject*
F test FE	16.29	7.84	9.88	8.75	2.25
(*p*-value)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0015)
BP LM test RE	1,189.30	56.9765	66.3799	125.6575	3.3304
(*p*-value)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.03401)
Hausman test	42.0311	52.4083	40.2340	27.4591	29.6695
(*p*-value)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0002)

[*] p-value< 0.1, ** p-value< 0.05, *** p-value< 0.01

[a] The numbers under each significant coefficient in parenthesis are the standard errors calculated on the basis of a bootstrap.

[b] *Nb obs* and *Nb groups* indicate respectively the number of observations and the corresponding cross-sectional units of the panel-data sample used to perform each regression. *F test FE* and *BP LM test RE* correspond respectively to the poolability tests of the FE model and the RE model against the pooled regression model which does not account for individual heterogeneity.

[c] The *Hausman test* tests the null hypothesis that the extra orthogonality conditions imposed by the RE estimator are valid. If the regressors are correlated with u_i, the FE estimator is consistent but the RE estimator is not consistent. If the regressors are uncorrelated with u_i, the FE estimator is still consistent, albeit inefficient, whereas the RE estimator is consistent and efficient.

tion) the more they cooperate. In heterogeneous groups, the more they get profit from the past period, the less they are incentivized to contribute to the group account since they would earn less.[43] The past advantageous inequality ((*l_adv_ineq*) is significant at the 5% level and influences negatively (positively) the rate of overcontribution in homogeneous (heterogeneous) groups. Advantageous inequality at the previous period decreases subjects *S*'s contribution, which reveals the incentive to free-ride in homogeneous groups. There seems to be no aversion to inequality in this situation where the payoffs are symmetric (subjects decide upon the same payoff tables). Though, the past advantageous inequality in heterogeneous groups increases the rate of overcontribution, which illustrates that even though subjects *S* tend to earn relatively more than subjects *C*, they experience a certain level of advantageous inequality aversion, in the sense that they dislike having a too much higher profit compared with their group member. Result 7 thus confirms Conjecture 4.

Result 7 *For subjects whose payoffs underlie perfect substitutability, an advantageous inequality aversion emerges when they interact with subjects whose payoffs underlie complementarity.*

Between-subject analysis: A past zero contribution from the subject (*l_freeriding*) influences positively the rate of overcontribution for both subjects *S* in homogeneous groups (significant at the 10% level) and subjects *C* in heterogeneous groups (significant at the 5% level), but for different reasons. A past zero contribution of the former increases the tendency to cooperation because subjects may observe positive contributions from some of their group members, which indicate that they could earn more. For the latter, it may be due to a learning effect *i.e.* trying to free-ride as a subject *C* is not a good strategy (reduces profit) whatever the other member contributes, except when the latter contributes more than 6 which is quite seldom (see bar charts in Figure 4). Past disadvantageous inequality (*l_disadv_ineq*) increases the rate of overcontribution for subjects *S* in homogeneous groups (significant at the 1% level) and for subjects *C* in heterogeneous groups (significant at the 10% level). This demonstrates a willingness to increase profit rather than a distaste of inequality. Subjects *C* do not sacrifice their profit by penalizing subjects *S* for earning relatively more. They rather seem to adapt to their payoff structure or hedge against low profits by contributing more even though their group member does not or does less. This contradicts Conjecture 5. This effect is less intuitive for subjects *S*. Being disadvantaged does not result in less contributions as would predict *(i)* an aversion to inequality or *(ii)* their incentive to free-ride. It cannot be interpreted as a hedging effect since the latter would be to free-ride in subjects *S* setting.

Anticipated advantageous inequality (*exp_adv_ineq*) is significant at the 1% level for all types and all treatments. It decreases the rate of overcontribution. When subjects believe that they will earn more than their group member, this decreases their contribution, suggesting

[43] This is in accordance with their negative gain to cooperation. See Table III.

their willing to free-ride. However, this is twice as more important for subjects S than for subjects C,[44] which is in line with their incentives. Anticipated disadvantageous inequality is also significant at the 1% level for all types and treatments. Expecting to earn less than one's group member increases the rate of overcontribution, which could be interpreted as a hedging effect for subjects C: by contributing more, they may hedge against the uncertain contribution of their group member. As for the past disadvantaged inequality, it is less intuitive for subjects S. Further analysis is necessary to conclude on the effects of both the past and anticipated disadvantageous inequality for subjects S.

5 Conclusions, limits and perspectives

This paper investigates *(i)* whether the structure of payoffs affects behavior in a voluntary contributions experiment, and *(ii)* whether the interaction of subjects with different structures of payoffs changes behavior compared with a situation in which subjects interact with their peers. Put differently, I examine whether there is a link between the CES specification (elasticity of substitution) and behavioral determinants. Regarding the first research question, I provide evidence that in homogeneous groups *i.e.* with symmetric payoffs, the rate of overcontribution is lower under complementarity than under substitutability between the private and the public goods. Therefore, the overcontribution pattern is mitigated by the complementarity structure, which is in line with the literature on interior Nash equilibrium. Additionally, free-riding occurs more often under perfect substitutability than under the complementarity structure, which is in line with the associated incentives to free-ride. Still some subjects with a low elasticity of substitution contribute zero, which suggests that they rely on the contribution of their group member to increase the public good level while they keep a high level of private good.

Within each structure of payoffs, I provide evidence for the second research question. Under perfect substitutability, subjects free-ride more often when they interact with the other type of subject (complementarity) for whom contributing positive amounts is optimal.

The free-riding results hold in both the non-parametric tests and the fixed effects model. The latter was performed to investigate the role of inequality aversion in the rate of overcontribution. It results that only subjects with a high elasticity of substitution experience aversion to advantageous inequality. In other words, advantageous inequality influences positively the rate of overcontribution. Another result is that the anticipated advantageous inequality effect on the rate of overcontribution is twice as much important under perfect substitutability as under complementarity. This is in line with the underlied constraints of the complementarity structure which requires an increase of both the private and the public goods to increase utility.

[44]The coefficients of Model (2) and Model (4) can be compared since their confidence intervals do not overlap (respectively [-0.0083162 ; -0.0077688] and [-0.0053558 ; -0.0030638]). Identically, the coefficients of Model (3) and Model (5) can be compared since the confidence intervals are [-0.0088809 ; -0.0082106] and [-0.0064517 ; -0.0023764] respectively.

The main limit of the results from this experiment is the order effect. Indeed, there seem to be confusion occurring in the counterbalanced order due to the homogeneous practice payoff table whereas subjects start the paying periods directly in heterogeneous groups. The design will be corrected so that subjects in the counterbalanced order get a heterogeneous practice payoff table whereas subjects in the regular order get a homogeneous payoff table. In other words, the practice payoff table must correspond to the first part of the experiment *i.e.* whether it is run in homogeneous or heterogeneous groups. Still, it seems harder to understand an asymmetric payoff table, which does not ensure the absence of order effects even after this adjustment. The end questionnaire and control questions of the experiment suggest that the instructions were clear enough to understand the game. Thus, the presentation of the payoff tables and the instructions will be kept as they are for the next larger experiment.

Some variables from the end questionnaire and the elicitation of risk aversion were not used in this analysis. Especially, risk aversion may affect the rate of overcontribution. The remaining problem is that such a dummy variable (whether subjects are risk-averse or not) is time-invariant. Thus, its effect on overcontributions cannot be analyzed with a FE model as the Hausman test recommends. The search for more appropriate models is necessary for further research. Also, the stability of beliefs have not been analyzed yet. A dynamic panel model may help determine this stability as well as provide a better analysis of the break from the homogeneous to the heterogeneous treatment over time.

Besides, it is possible that a larger proportion of free-riders was assigned to type C or type S. To control for such a problem, a one-shot dictator game may be run before starting the game in order to spread evenly across the two types the subjects identified as free-riders.

An analysis of confusion would be interesting in this rather pioneering design. Anderson et al. (2008) provide the logit equilibrium model[45] which allows for the investigation of the error hypothesis and altruism which are questions of interest here. This model explains Nash-like behavior in some contexts and deviations from the Nash equilibrium in others. It has been used for example by Willinger and Ziegelmeyer (2001).

A similar experiment in the context of climate change may provide insight into climate change negotiations. The main difference in the results would lie in the fact that some individuals care for the environment while others do not.

Finally, for further research, this experiment could be adapted for an analysis of wealth

[45]"*This approach involves introducing random elements, interpreted as either bounded rationality or unobserved preference shocks, into an equilibrium analysis. Individuals' choices are assumed to be positively, but not perfectly, related to expected payoffs, in that decisions with higher expected payoffs are more likely to be selected. With repeated (random) matchings, the choice probabilities of one player will affect the beliefs, and hence the expected payoffs, of others. The equilibrium is a fixed point: the choice probabilities that determine expected payoffs correspond to the probabilities determined by expected payoffs via a probabilistic choice rule (Rosenthal, 1989; McKelvey and Palfrey, 1995). The degree of bounded rationality is described by an error parameter, and the equilibrium probabilities converge to a Nash equilibrium as this parameter goes to zero.*" (Anderson et al., 2008, p.550).

effects and wealth inequality effects on the contributions to the public good, as interestingly raised in Baumgärtner et al. (2017).

Appendices

A Solving for Nash equilibrium

Player 1 (resp. 2) is expected to maximize her own utility taking player's 2 (resp. 1) contribution as given. Therefore, we solve:

$$\max_{y_1} u_1(x_1, y) \qquad \text{s.t.} \qquad x_1 + y_1 = w_1 \tag{20}$$

Substituting the budget constraint and the public good provision expression $y = y_1 + y_2$ into player's utility function, we get

$$u_1(x_1, y) = u_1(w_1 - y_1, y_1 + y_2) = \Bigg(\underbrace{\alpha(w_1 - y_1)^{\gamma_1} + (1-\alpha)(y_1 + y_2)^{\gamma 1}}_{A}\Bigg)^{\frac{1}{\gamma_1}}.$$

FOC (Nash):

$$\begin{aligned}\frac{\partial u_1}{\partial y_1} &= 0\\ &= \frac{1}{\gamma_1} A^{\frac{1}{\gamma_1}-1}\left(-\alpha\gamma_1(w_1 - y_1)^{\gamma_1 - 1} + (1-\alpha)(y_1 + y_2)^{\gamma_1 - 1}\right)\end{aligned}$$

with $A^{\frac{1}{\gamma_1}-1} \neq 0$ and $\frac{1}{\gamma_1} \neq 0$.

$$\frac{\partial u_1}{\partial y_1} = 0 \tag{21}$$

$$\Leftrightarrow -\alpha\gamma_1(w_1 - y_1)^{\gamma_1 - 1} + (1-\alpha)(y_1 + y_2 + q)^{\gamma_1 - 1} = 0 \tag{22}$$

$$\Leftrightarrow \alpha\gamma_1(w_1 - y_1)^{\gamma_1 - 1} = (1-\alpha)(y_1 + y_2 + q)^{\gamma_1 - 1} \tag{23}$$

$$\Leftrightarrow \left(\frac{w_1 - y_1}{y_1 + y_2 + q}\right)^{\gamma_1 - 1} = \frac{1-\alpha}{\alpha} \tag{24}$$

$$\Leftrightarrow w_1 - y_1 = \underbrace{\left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\gamma_1 - 1}}}_{\mu_1}(y_1 + y_2 + q) \tag{25}$$

$$\Leftrightarrow w_1 - \mu_1(y_2 + q) = y_1(1 + \mu_1) \tag{26}$$

$$\Leftrightarrow y_1^* = \frac{w_1 - \mu_1(y_2 + q)}{1 + \mu_1} \tag{27}$$

y_1^* is the best response function of player 1 to any strategy y_2 of player 2.

Symmetrically, $y_2^* = \frac{w_2 - \mu_2(y_1+q)}{1+\mu_2}$ with $\mu_2 = \left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\gamma_2 - 1}}$.

The Nash equilibrium is the intersection between the two best response curves so that it is the solution of the following system:

$$\begin{cases} y_1^* = \frac{w_1 - \mu_1(y_2+q)}{1+\mu_1} \\ y_2^* = \frac{w_2 - \mu_2(y_1+q)}{1+\mu_2} \end{cases}$$

By substituting y_2 in y_1 and isolating y_1, we get:

$$y_1^* = \frac{1}{1+\mu_1+\mu_2}\left((1+\mu_2)w_1 - \mu_1 w_2 - \mu_1\, q\right) \tag{28}$$

homogeneous case: If players have the same payoff structure, then $\mu_1 = \mu_2 = \mu$. Since $w_1 = w_2 = w$, the Nash equilibrium is as follows:

$$y_1^* = y_2^* = \frac{1}{1+2\mu}(w - \mu\, q) \tag{29}$$

heterogeneous case: Consider that player 1 has an elasticity of substitution which tends to infinity ($\varepsilon_1 \to \infty$ or $\gamma - 1 \to 1$ *i.e.* perfect substitutability case). It is equivalent to solve the Nash equilibrium by considering a linear utility function for Player 1 (*i.e.* the right extreme case of a CES function). Then Player 1 and Player 2 have the following respective payoffs:

$$\begin{cases} u_1(x_1, y) = \left(\alpha x_2^{\gamma_1} + (1-\alpha) y^{\gamma_1}\right)^{\frac{1}{\gamma_1}} \\ u_2(x_2, y) = \left(\alpha x_2^{\gamma_2} + (1-\alpha) y^{\gamma_2}\right)^{\frac{1}{\gamma_2}} \end{cases}$$

Player 1's best strategy is to contribute zero to the public good (standard linear public good game Nash equilibrium) hence $y_1^* = 0$.

y_2^* (as derived in Eq. (27)) is the best response function of Player 2 to any strategy y_1 of Player 1 such that $y_2^* = \frac{w_2}{1+\mu_2} - \frac{\mu_2}{1+\mu_2}(y_1^* + q)$.

Thus, the Nash equilibrium is such that:

$$\begin{cases} y_1^* = 0 \\ y_2^* = \frac{w_2}{1+\mu} - \frac{\mu}{1+\mu} q \end{cases}$$

with $\mu = \left(\frac{1-\alpha}{\alpha}\right)^{\frac{1}{\gamma - 1}}$.

B Solving for Pareto optima

The level of public good provision is found by using the Samuelson rule, the feasibility rule and the allocation rule.
The Samuelson rule states that the sum of the marginal rates of substitution equals the marginal rate of transformation (prices ratio).
Since

$$\forall\, i \begin{cases} \frac{\partial u_i}{\partial x_i} = \frac{K}{\gamma_i} A^{\frac{1}{\gamma_i}-1}\ \gamma_i\, \alpha\, x_i^{\gamma_i - 1} \\ \frac{\partial u_i}{\partial y} = \frac{K}{\gamma_i} A^{\frac{1}{\gamma_i}-1}\ \gamma_i (1-\alpha)\, y^{\gamma_i - 1} \end{cases}$$

Then $MRS^i_{y/x} = \frac{\frac{\partial u_i}{\partial y}}{\frac{\partial u_i}{\partial x_i}} = \frac{1-\alpha}{\alpha} \left(\frac{y}{x_i}\right)^{\gamma_i - 1}$.

Since $p_{x_i} = p_y = 1\ \forall\ i$ in a public good experiment (because x_i and y_i are respectively considered as investments in a private good and a public good) then the Samuelson rule results in:

$$\begin{aligned} MRS^1_{y/x} + MRS^2_{y/x} = 1 \Leftrightarrow \frac{1-\alpha}{\alpha}\left(\frac{x_1}{y}\right)^{1-\gamma_1} + \frac{1-\alpha}{\alpha}\left(\frac{x_2}{y}\right)^{1-\gamma_2} &= 1 \\ \Leftrightarrow \left(\frac{x_1}{y}\right)^{1-\gamma_1} + \left(\frac{x_2}{y}\right)^{1-\gamma_2} &= \frac{\alpha}{1-\alpha} \end{aligned}$$

The feasibility rule consists in the set of budget constraints such that:

$$\begin{cases} x_1 + y_1 = w_1 \\ x_2 + y_2 = w_2 \end{cases}$$

The budget constraints can add up and give: $x_1 + x_2 = w_1 + w_2 - y_1 - y_2$.

What I call the allocation rule represents the total public good provision y derived from the two private contributions by players y_1 and y_2.

$$y = y_1 + y_2 + q \Leftrightarrow \begin{cases} y_1 = \theta(y-q) \\ y_2 = (1-\theta)(y-q) \end{cases}$$

with $\theta \in [0,1]$ the share of player's 1 contribution to the public good. A particular case is when the game is homogeneous such that $\theta = \frac{1}{2}$ or equivalently $y_1 = y_2$.

Note that the following constraints always hold:

$$\begin{cases} q \geq 0 \\ w_1,\ w_2 > 0 \\ q \leq y \leq w_1 + w_2 + q \\ 0 < \alpha < 1 \\ x_1,\ x_2,\ y_1,\ y_2 \geq 0 \end{cases}$$

Combining the three rules simplifies the Samuelson rule into:

$$\left(\frac{w_1 - \theta(y-q)}{y}\right)^{1-\gamma_1} + \left(\frac{w_2 - (1-\theta)(y-q)}{y}\right)^{1-\gamma_2} = \frac{\alpha}{1-\alpha} \tag{30}$$

which can be rewritten as follows since endowments are identical:

$$y^{\gamma_1 - 1}\left(w_\theta(y-q)\right)^{1-\gamma_1} + y^{\gamma_2 - 1}\left(w - (1-\theta)(y-q)\right)^{1-\gamma_2} = \frac{\alpha}{1-\alpha} \tag{31}$$

Eq. (31) represents the general heterogeneous contributions case (because different payoff structures) which applies in Treatment $S \times C$.

homogeneous case: The particular case of symmetric contributions, such that $\theta = \frac{1}{2}$ or equivalently $y_1 = y_2$, applies to Treatments S and C, and leads to the following socially optimal (abbreviated by *s.o.*) below) public good level:

$$y^{s.o} = \frac{(\theta\, q + w)\,(2(1-\alpha))^{\frac{1}{1-\gamma}}}{\alpha^{\frac{1}{1-\gamma}} + \frac{1}{2}\,(2(1-\alpha))^{\frac{1}{1-\gamma}}} \tag{32}$$

Then social contributions are then straightforward:

$$y_1^{s.o.} = y_2^{s.o.} = \frac{1}{2}(y^{s.o} - q) \tag{33}$$

It can be checked in Figure 7 that the Nash level of the public good is below every social level of the public good, which characterizes the social dilemma.

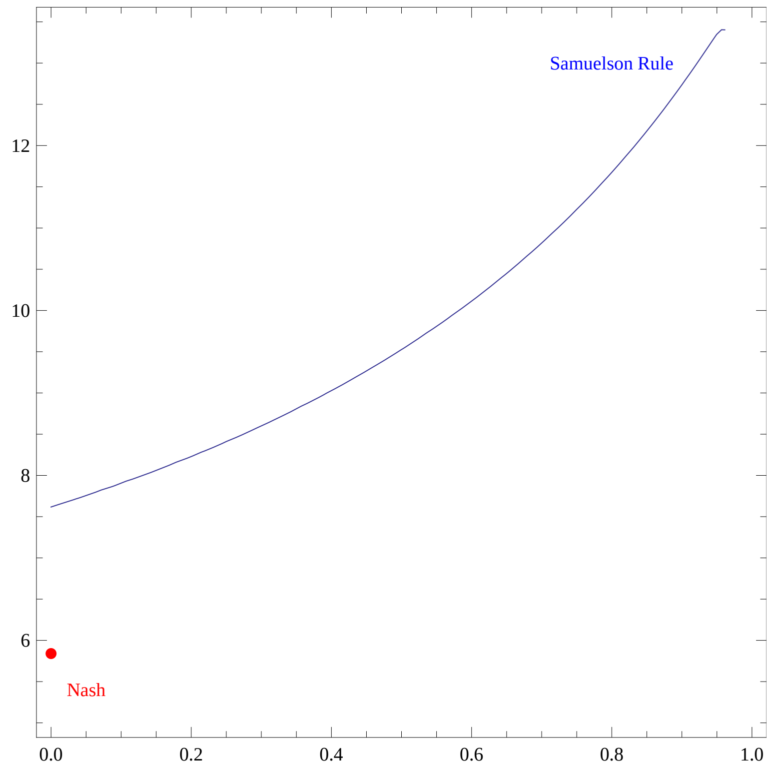


Figure 7: Nash equilibrium and (θ, y) combinations satisfying the Samuelson rule

C Compressed payoff table format

YOUR CONTRIBUTION

THE OTHER GROUP MEMBER'S CONTRIBUTION

Perso ↓	Group ↓	Perso 12 / Group 0	Perso 10 / Group 2	Perso 8 / Group 4	Perso 6 / Group 6	Perso 4 / Group 8	Perso 2 / Group 10	Perso 0 / Group 12
12	0	264 / 264	253 / 291	243 / 321	233 / 355	225 / 392	217 / 434	209 / 480
10	2	291 / 253	278 / 278	266 / 306	255 / 338	244 / 374	235 / 414	226 / 458
8	4	321 / 243	306 / 266	292 / 292	280 / 323	267 / 357	256 / 395	245 / 437
6	6	355 / 233	338 / 255	323 / 280	308 / 308	294 / 340	281 / 376	269 / 417
4	8	392 / 225	374 / 244	357 / 267	340 / 294	325 / 325	310 / 359	296 / 397
2	10	434 / 217	414 / 235	395 / 256	376 / 281	359 / 310	342 / 342	326 / 379
0	12	480 / 209	458 / 226	437 / 245	417 / 269	397 / 296	379 / 326	361 / 361

Figure 8: Compressed payoff table provided to participants in Treatment *C*

YOUR CONTRIBUTION

THE OTHER GROUP MEMBER'S CONTRIBUTION

Perso →		12	10	8	6	4	2	0
↓	Group → ↓	0	2	4	6	8	10	12
12	0	170 170	206 213	232 269	233 325	215 380	187 431	170 480
10	2	213 206	251 251	263 294	252 335	223 374	189 410	170 444
8	4	269 232	294 263	292 292	268 319	230 344	190 367	170 389
6	6	325 233	335 252	319 268	283 283	236 297	192 310	170 322
4	8	380 215	374 223	344 230	297 236	242 242	193 247	170 252
2	10	431 187	410 189	367 190	310 192	247 193	194 194	170 195
0	12	480 170	444 170	389 170	322 170	252 170	195 170	170 170

Figure 9: Compressed payoff table provided to participants in Treatment C

YOUR CONTRIBUTION

THE OTHER GROUP MEMBER'S CONTRIBUTION

Perso →		12	10	8	6	4	2	0
↓	Group → ↓	0	2	4	6	8	10	12
12	0	264 170	253 213	243 269	233 325	225 380	217 431	209 480
10	2	291 206	278 251	266 294	255 335	244 374	235 410	226 444
8	4	321 232	306 263	292 292	280 319	267 344	256 367	245 389
6	6	355 233	338 252	323 268	308 283	294 297	281 310	269 322
4	8	392 215	374 223	357 230	340 236	325 242	310 247	296 252
2	10	434 187	414 189	395 190	376 192	359 193	342 194	326 195
0	12	480 170	458 170	437 170	417 170	397 170	379 170	361 170

Figure 10: Compressed payoff table provided to participants in Treatment S in Treatment $S \times C$

D Instructions given to participants

Welcome to the lab!

You are now taking part in an experiment on decision making. Please, do not communicate with others during the experiment; we will have to stop all the experiment if one of you communicates. If you have questions, do not hesitate to ask an experimenter who will answer you in private.

OUTLINE OF THE EXPERIMENT

In this experiment, you will work in **pairs**. This means you will always be in a group of 2 persons including you. The other member of your group will be selected randomly by computer and will change at each period (22 periods in total).
You will not know who you are paired with in the room.

You will be endowed with **12 Experimental Money Units (EMUs)** for each period. Your group member also has 12 EMUs for each period. The conversion rate from EMU to SEK is the following:

1 EMU = 0.45 SEK

You have two accounts at each period. A **Personal account** which is only yours, and a **Group account** which belongs to both you and your group member.

You will have to decide how many EMUs you want to contribute (between 0 and 12) to the Group account. The EMUs you invest in the **Group account** will both benefit you and the other member of your group. The EMUs you do not contribute are automatically invested in your Personal account (so 12 - Your contribution to the Group account). The EMUs invested in your **Personal account** only benefit you, not the other group member. Therefore, your payoff in each period depends on:

1. **Your contribution to the Group account,**
2. **What you indirectly place in your Personal account** (the amount of EMUs you did not contribute to the Group account),
3. **Your group member's contribution to the Group account.**

In other words, **your payoff depends on your choice (how you allocate your EMUs between the Group and the Personal account) and your group member's choice**. In total, there will be 22 periods (2 practice periods and 20 paying periods).

Your payoff at each period is indicated in a detailed Payoff Table. Note that you received 2 Payoff Tables: a compressed Payoff Table and a detailed Payoff Table. *The compressed Table is a reduced form of the detailed Table.*

There will be **two parts** in this experiment from which you get paid. Your earnings will be calculated as follows. Two periods will be randomly selected by computer: one period from Part 1 and one period from Part 2. **Your earnings will be your average payoff from these two periods**. At the end of the experiment, your earnings will be given to you in cash in private (nobody will get to know how much you earnt).

Please check that you received the following items on your desk:

- "Instructions" (this sheet)
- Writing materials (pencil, paper)
- 2 "Practice" Payoff Tables (one compressed and one detailed)
- A "Payment Confirmation" sheet (for the end of the experiment)

DESCRIPTION OF THE EXPERIMENT

This experiment consists of the Practice Part, Part 1 and Part 2. The practice part runs for 2 periods (1 and 2) from which you do not get paid. Part 1 runs from Period 3 to Period 12 (10 periods). Part 2 runs from period 13 to period 22 (10 periods). The instructions of Part 1 and Part 2 will be given on the computer screen.

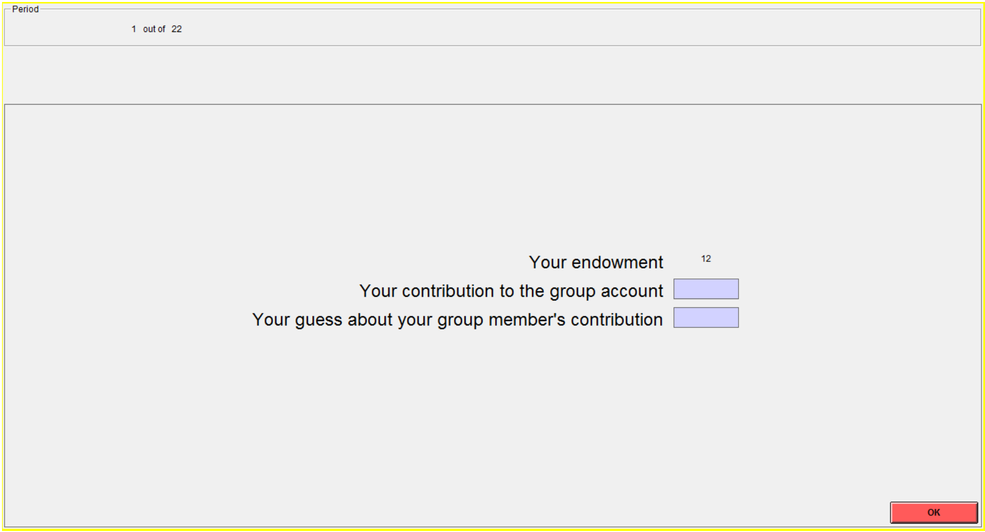
In every part of the experiment, you decide at each period how much you want to contribute to the Group account between 0 and 12 using the Payoff Tables indicated by the computer (you will use a different pair of Payoff Tables in the Practice part, Part 1 and Part 2). All participants to the experiment will decide at the same time. Therefore, you will not know how much your group member contributes before the end of each period.

You will see the following screen at each period. Note that you have to enter the following items to validate your choice.

- Your contribution to the Group account (a number between 0 and 12)
- How much you think your group member will contribute (between 0 and 12 as well)

Once you filled these items, press the "OK" button to see your results. **Once you press the "OK" button, you cannot modify your decision anymore**.

For Part 1 and Part 2, you will have to write down your decisions and payoffs on a "Record Sheet" which will be given to you. This will allow you to keep track of your



decisions. The computer will remind it to you at each period. Note that the period number is displayed at the top left of the screen.
Once all participants have entered their decisions on the computer, the results (your payoff from this period and the contribution of your group member) will be displayed on the screen. Note that you can always check your resulting payoff in the Payoff Table.

In the next period, your group member changes randomly and you will not know who she/he is in the room.

The Payoff Tables

Please, take the "Practice" Payoff Tables. I will now explain how to read a Payoff Table.

In each part of the experiment, you have two Payoff Tables:

- The first one is a compressed Payoff Table. You can check that the contributions displayed in dark red and dark blue cells are only even numbers (0, 2, 4, 6, 8, 10 and 12).
- The second Payoff Table is the corresponding detailed Payoff Table (which displays all possible contributions from 0 to 12 and the associated payoffs).

The compressed Payoff Table (the first one) is only here if you feel uncomfortable at first sight with the detailed Payoff table (the second one). The compressed Payoff Table allows you to get used to reading a Payoff Table but is not enough to make your decision. You must **make your decision with the detailed Payoff Table** because your contribution can be any number between 0 and 12 (not only even numbers).

Like the contributions, the payoffs at each period are displayed in EMUs in the Payoff Table.

Now, look at the slideshow.

In the Payoff Table, **the row filled in dark red shows your possible contributions to the Group account** and the light red row above it shows your corresponding amount of EMUs assigned to your Personal Account (so 12 - your contribution to the Group account). Symmetrically, **the column filled in dark blue in the table shows your group member's possible contributions to the Group account**, and the column filled in light blue on the left shows his/her Personal EMUs.

The light red row and the light blue column are only here for information about what your payoff takes into account. Your choice only relies on the dark red row; the choice of your group member only relies on the dark blue column.

Inside the table, each cell displays two pieces of information to help you decide on how much you want to contribute:

1. **your potential payoffs (red numbers on the left),**
2. **the other group member's potential payoffs (blue numbers on the right).**

Your group member also has these two pieces of information. Whatever the part you go through, the blue numbers in your Payoff Table are your group member's red numbers in her/his Payoff Table, and vice-versa, whatever your group member sees as blue, you will see as red.

Now, I will go through 4 examples.

Example 1: suppose you contribute 7 and your group member contributes 8. You have to find the column corresponding to 7 and the row corresponding to 8. Your payoff and your group member's payoff will be in the cell where the two lines intersect. In this example, in red, your payoff is "134" and in blue, your group member's payoff is "126".

Example 2: suppose your group member contributes 2 and you decide to contribute 1. You have to find the row corresponding to 2 and the column corresponding to 1. This would result in your payoff being "122" (in red) and your group member's payoff being "117" (in blue).

Example 3: during the task, if you think that your group member will contribute 3, then

- by contributing 0 –> you get "127" & she/he gets "112"
- by contributing 2 –> you get "128" & she/he gets "123"
- by contributing 5 –> you get "124" & she/he gets "136"
- by contributing 9 –> you get "109" & she/he gets "151"
- by contributing 12 –> you get "74" & she/he gets "162"

Example 4: if you think that your group member will contribute 8, then

- by contributing 1 –> you get "152" & she/he gets "108"
- by contributing 6 –> you get "138" & she/he gets "123"
- by contributing 12 –> you get "82" & she/he gets "139"

Your earnings

Your earnings will depend on the two random periods, say 6 and 17 for example, selected by the computer at the end of the experiment. Your earnings are calculated as follows:

$$Earnings = Show\text{-}up\ Fee + \frac{Payoff_6 + Payoff_{17}}{2} \times 0.45 \quad \text{SEK} \tag{34}$$

The Show-up fee is 50 SEK. This is the same amount for all participants. You will potentially earn more in two additional tasks that will be explained on the computer screen.

The experiment is about to commence. Now please follow the instructions on your computer.

The following instructions were directly given on the computer screen. Note that the counterbalanced order was exactly the same as the regular order provided below except that Part 1 consisted in Part 2 and Part 2 consisted in Part 1

ONE PRELIMINARY QUESTION

Before we start the task that was explained to you, please answer the following question. Depending on your choice, you can earn an amount of money which will be added to your experimental earnings.

In this task, we give you an amount of 45 EMUs. You have to decide how much of this amount (between 0 and 45) you wish to place in the following lottery.

You have a chance of 2/3 (67%) to lose the amount you invest and a chance of 1/3 (33%) to win two and a half times the amount you invest.

The amount you do not place in the lottery (so 45 - what you invest) directly goes to your earnings. Your earnings from this task will only depend on your choice and the random number the computer selects between 0 and 100.

- If the computer picks a number between 0 and 67, you earn the amount you did not invest only,
- If the computer picks a number between 68 and 100, you earn what you did not invest plus two and a half times the amount you invested.

CONTROL QUESTIONS

Before starting the game, please answer the following questions. These questions will ensure that everyone understands the task. The correct answers will be given by the computer after you answer all questions.

This is important that you understand the game. So, raise your hand if you have any question and wait for someone to come to you.

Please use the "Practice" Payoff Table to answer the questions and follow the computer's instructions.

After you answer all questions, click "Submit" to check the correct answers. Take your time if some of your answers are wrong to understand why you made mistakes This will ensure that you understand the game.

1. Endowment
   (a) How many Experimental Money Units (EMUs) are you endowed with at each period? .....
   (b) How many EMUs does your group member have at each period? .....
2. If you decide to contribute 8 to the Group account and the other player contributes 9,
   (a) how much do you earn? .....
   (b) how much does the other player get? .....

3. If you decide to contribute 0 to the Group account and the other player contributes 4,
    (a) what are your earnings? .....
    (b) what are his/her earnings? .....
4. If you think your group member will contribute 3 and you decide to contribute 2 to the Group account,
    (a) what would be your expected earnings? .....
    (b) what would be his/her expected earnings? .....
5. If you think your group member will contribute 10 and you decide to contribute 10 tokens to the Group account,
    (a) what would be your expected earnings? .....
    (b) what would be his/her expected earnings? .....

PRACTICE

Consider the **Payoff Tables labelled "Practice"** to make your decision for the following 2 periods.
These 2 periods will not be paid, they are only for practicel. They ensure that you understand the task before the paying periods start. Follow the instructions on the computer.

THE EXPERIMENT

PART 1

Now you are entering PART 1.
Please return the "Practice" Payoff Tables (keep the "Instructions" with you). We will give you a different envelope. Open the new envelope and check that you received the following items:

- 2 Payoff Tables labelled "PART 1",
- A "Record Sheet".

Write down on your **"Record Sheet"** Subject number (which is displayed above). At each period, you have to fill out the "Record Sheet" to keep track of your decisions.
This means that the following periods affect your earnings.

In this part, for given contributions from you and your group member, you and your group member have the same payoffs.
For example, you can check in your Payoff Table that, if both of you contribute 6, you get the same payoffs. Another example: if you contribute 2 and your group member contributes 3, your payoff is the same as your group member's payoff when she/he contributes 2 and you contribute 3.
This means that you decide upon the same Payoff Tables.
Take 5 minutes to review the Payoff Tables you have just received.
Raise your hand if you have a question, an experimenter will come to you.

PART 2

Now you are entering PART 2.
Please, return the Payoff Tables labelled "PART 1". We will give you a new envelope.
Check that you received two Payoff Tables labelled "PART 2".
Your payoffs are the same compared with PART 1 (same red numbers), but your group member's payoffs are different (different blue numbers compared with PART 1)
In this part, for given contributions from you and your group member, you and your group member have different payoffs.
For example, you can check in your Payoff Table that, if both of you contribute 6, you get different payoffs whereas these payoffs were the same in PART 1. Another example: if you contribute 2 and your group member contributes 3, your payoff is different from your group member's payoff when she/he contributes 2 and you contribute 3.
Take 5 minutes to read the new Payoff Tables.

E Order effects: visual inspection

Figure 12 shows mean contributions over time for the counterbalanced order *i.e.* in which players were first in heterogeneous then in homogeneous groups. The results are less stringent in the counterbalanced order. In heterogeneous groups (left part of the graoh), subjects *C* seem to globally contribute more than subjects *S* as observed previously but the difference is lower. In homogeneous groups (right part of the graph), this is not clear whether subjects *S* contribute more or less than subjects *C* as observed in the regular order.

The counterbalanced order may be more confusing to subjects. This may be easier to start with the information that co-players decide upon the same payoff table as in the regular order. Another explanation can be that the practice payoff table was the same in the regular and the

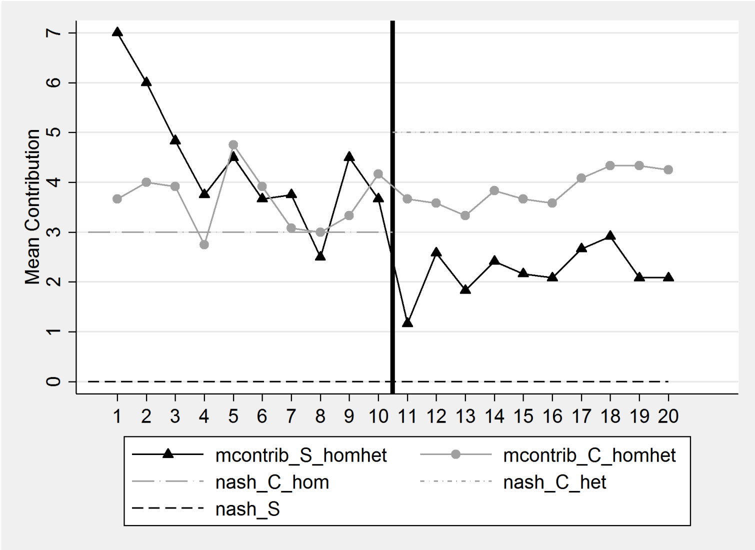


Figure 11: Mean contributions over periods - homogeneous -> heterogeneous[46]

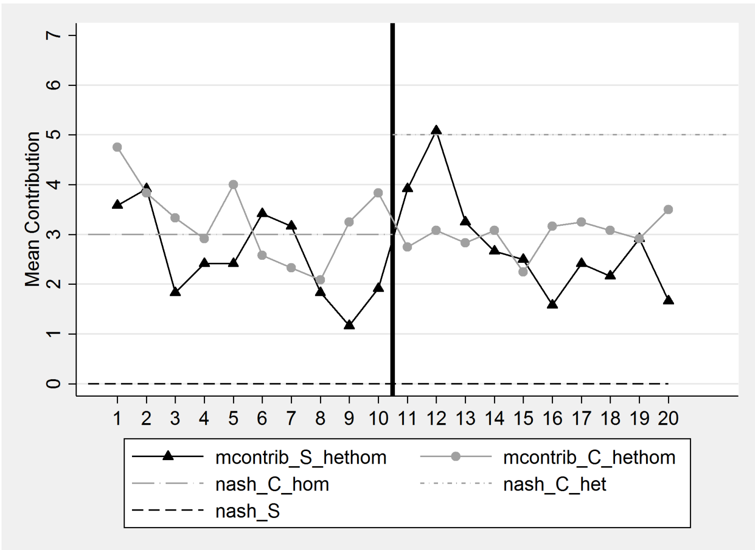


Figure 12: Mean contributions over periods - heterogeneous -> homogeneous

counterbalanced orders. This was a symmetric payoff table, which means that the practice table corresponded to the first part of the experiment in the regular order but to the second part in the counterbalanced order.

F Econometric tests

F.1 Panel Stata results: FE vs RE models

Variable	rFE_G	rRE_G	rFE_S_hom	rRE_S_hom	rFE_S_het	rRE_S_het	rFE_C_hom	rRE_C_hom	rFE_C_het	rRE_C_het
heterogenous	-0.1207***	-0.1208***								
l_memberovercontribution	-0.0538***	-0.0598***	0.0158***	0.0153***	-0.0138**	-0.0130**				
exp_disadv_ineq	0.0051***	0.0052***	0.0061***	0.0060***	0.0064***	0.0062***	0.0048***	0.0050***	0.0060***	0.0059***
exp_adv_ineq	-0.0057***	-0.0057***	-0.0080***	-0.0081***	-0.0085***	-0.0086***	-0.0042***	-0.0038***	-0.0044***	-0.0037***
expprofit	0.0060***	0.0062***	0.0104***	0.0104***	0.0113***	0.0114***	0.0033***	0.0032**	0.0040***	0.0039***
l_disadv_ineq			0.0001**	0.0001					0.0007*	0.0003
l_profit					-0.0002**	-0.0001				
l_adv_ineq					0.0003**	0.0002**				
l_freeriding									0.1170**	0.0252
Constant	-1.5145***	-1.5607***	-2.7196***	-2.7268***	-2.9219***	-2.9543***	-0.8672***	-0.8252**	-1.3810***	-1.3236***
N	912	912	228	228	228	228	240	240	228	228
sigma_u	0.1391	0.0967	0.0320	0.0224	0.0257	0.0122	0.1128	0.0652	0.0989	0.0076
sigma_e	0.1374	0.1374	0.0272	0.0272	0.0164	0.0164	0.1073	0.1073	0.1683	0.1683
rho	0.5061	0.3311	0.5806	0.4042	0.7098	0.3546	0.5248	0.2694	0.2566	0.0021
rmse	0.1374	0.1404	0.0272	0.0280	0.0164	0.0179	0.1073	0.1134	0.1683	0.1786
r2_w	0.7077	0.7071	0.9871	0.9869	0.9895	0.9890	0.6473	0.6437	0.6982	0.6832
r2_b	0.6361	0.6524	0.9849	0.9866	0.9917	0.9940	0.0697	0.0870	0.5775	0.6947
r2_o	0.6746	0.6818	0.9856	0.9866	0.9897	0.9914	0.4388	0.4557	0.6607	0.6817
r2_a	0.6900		0.9852		0.9879		0.6043		0.6557	
F_f	16.2919		9.0733		9.8789		8.7509		2.2500	
chi2	711.5874	813.0869	6.4e+03	6.1e+03	4.8e+03	5.2e+03	175.8675	229.2645	502.3517	188.7914

legend: * p<.1; ** p<.05; *** p<.01

Figure 13: (robust) Fixed effects and random effects models results from Stata

F.2 Panel Stata results: crossed-variables

Variable	rFE_G	rRE_G
exp_adv_ineq_C_het	-0.0045***	-0.0047***
l_profit_S_het	-0.0003***	-0.0010***
expprofit_S_hom	0.0105***	0.0060***
l_disadv_ineq_S_hom	0.0001***	0.0003*
expprofit_C_hom	0.0045***	0.0055***
exp_adv_ineq_C_hom	-0.0049***	-0.0050***
expprofit_S_het	0.0107***	0.0069***
exp_adv_ineq_S_het	-0.0082***	-0.0059***
exp_disadv_ineq_S_het	0.0062***	0.0050***
exp_disadv_ineq_S_hom	0.0061***	0.0045***
exp_disadv_ineq_C_het	0.0057***	0.0061***
exp_adv_ineq_S_hom	-0.0081***	-0.0052***
exp_disadv_ineq_C_hom	0.0053***	0.0061***
l_memberovercontrib~S_hom	0.0143**	0.0764**
expprofit_C_het	0.0035***	0.0046***
l_adv_ineq_S_het	0.0002**	0.0010***
Constant	-1.9598***	-1.4899***
N	912	912
sigma_u	0.7953	0.0275
sigma_e	0.1054	0.1054
rho	0.9827	0.0638
rmse	0.1054	0.1242
r2_w	0.8302	0.7864
r2_b	0.6843	0.9163
r2_o	0.4880	0.8429
r2_a	0.8176	
F_f	12.3324	
chi2	1.3e+04	1.5e+03

Figure 14: (robust) FE and RE models results from Stata for the general model with crossed-variables

References

Ahmed, S. (1986). “Temporary and permanent government spending in an open economy: Some evidence for the United Kingdom”. *Journal of Monetary Economics* 17.2, pp. 197–224.

Anderson, S. P., J. K. Goeree, and C. A. Holt (2008). “Chapter 61 Logit Equilibrium Models of Anomalous Behavior: What to do when the Nash Equilibrium Says One Thing and the Data Say Something Else”. *Handbook of Experimental Economics Results*. Vol. 1. Chap. 61, pp. 549–558.

Andreoni, J. (1993). “An experimental test of the public-goods crowding-out hypothesis”. *American Economic Review* 83.5, pp. 1317–1327.

Andreoni, J. and R. Croson (2008). “Chapter 82 Partners versus Strangers: Random Rematching in Public Goods Experiments”. *Handbook of Experimental Economics Results*. Ed. by C. R. Plott and V. L. Smith. Vol. 1, pp. 776–783.

Arent, D. J., R. S. Tol, E. Faust, J. P. Hella, S. Kumar, K. M. Strzepek, F. L. Tóth, and D. Yan (2014). "Key economic sectors and services". *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, pp. 659–708.

Aschauer, D. A. (1985). "Fiscal Policy and Aggregate Demand". *American Economic Review* 75.1, pp. 117–127.

Baumgärtner, S., M. A. Drupp, J. N. Meya, J. M. Munz, and M. F. Quaas (2017). "Income inequality and willingness to pay for environmental public goods". *Journal of Environmental Economics and Management* 85, pp. 35–61.

Bracha, A., M. Menietti, and L. Vesterlund (2011). "Seeds to succeed? Sequential giving to public projects". *Journal of Public Economics* 95.5-6, pp. 416–427.

Burke, M., S. M. Hsiang, and E. Miguel (2015). "Global non-linear effect of temperature on economic production". *Nature* 1, pp. 1–16.

Cason, T. N. and L. Gangadharan (2015). "Promoting cooperation in nonlinear social dilemmas through peer punishment". *Experimental Economics* 18, pp. 66–88.

Cason, T. N., T. Saijo, and T. Yamato (2002). "Voluntary Participation and Spite in Public Good Provision Experiments: An International Comparison". *Experimental Economics* 5, pp. 133–153.

Chan, K. S., S. Mestelman, R. Moir, and R. A. Muller (1999). "Heterogeneity and the voluntary provision of public goods". *Experimental Economics* 2.1, pp. 5–30.

Charness, G., U. Gneezy, and A. Imas (2013). "Experimental methods: Eliciting risk preferences". *Journal of Economic Behavior and Organization* 87, pp. 43–51.

Costinot, A., D. Donaldson, and C. Smith (2016). "Evolving Comparative Advantage and the Impact of Climate Change in Agricultural Markets: Evidence from a 9 Million-Field Partition of the Earth". *Journal of Political Economy, Forthcoming* 124.1.

Fehr, E and K. Schmidt (1999). "A theory of fairness, competition, and cooperation". *The quarterly journal of economics* August, pp. 817–868.

Fiorito, R. and T. Kollintzas (2004). "Public goods, merit goods, and the relation between private and government consumption". *European Economic Review* 48.6, pp. 1367–1398.

Fischbacher, U. (2007). "Z-Tree: Zurich toolbox for ready-made economic experiments". *Experimental Economics* 10.2, pp. 171–178.

Gerlagh, R. and B. van der Zwaan (2002). "Long-Term Substitutability between Environmental and Man-Made Goods". *Journal of Environmental Economics and Management* 44.2, pp. 329–345.

Giraudet, L.-G. and C. Guivarch (2016). "Global Warming as a Public Bad". *FAERE Working Paper 2016.26*. Working Paper.

Gneezy, U. and J. Potters (1997). "An Experiment on Risk Taking and Evaluation Periods". *Quarterly Journal of Economics* 112.2, pp. 631–645.

Greiner, B. (2004). "The Online Recruitment System ORSEE 2.0 - A Guide for the Organization of Experiments in Economics". *Working Paper Series in Economics*.

Isaac, R. M. (1991). "On the suboptimality of voluntary public goods provision : further experimental evidence". *Research in experimental economics : a research annual* 4.

Isaac, R. M. and J. M. Walker (1998). "Nash as an organizing principle in the voluntary provision of public goods: Experimental evidence". *Experimental Economics* 1.3, pp. 191–206.

Karras, G. (1996). "Government Spending and Private Consumption : Some International Evidence". *Journal of Money, Credit and Banking* 26.1, pp. 9–22.

Keser, C. (1996). "Voluntary contributions to a public good when partial contribution is a dominant strategy". *Economics Letters* 50.3, pp. 359–366.

Laury, S. K. and C. a. Holt (2008). "Voluntary Provision of Public Goods : Experimental Results with Interior Nash Equilibria". *Handbook of Experimental Economics Results* 1.June, pp. 792–801.

Moffatt, P. G. (2015). *Experimetrics: Econometrics for Experimental Economics*. Palgrave Macmillan.

Neumayer, E. (1999). "Global warming: discounting is not the issue, but substitutability is". *Energy Policy* 27.1, pp. 33–43.

Ostrom, E. (2000). "Collective Action and the Evolution of Social Norms". *Journal of Economic Perspectives* 14.3, pp. 137–158.

Ostrom, E., J. Walker, and R. O. Y. Gardner (1992). "Covenants With and Without a Sword : Self-Governance is Possible". *American Political Science Review* 86.2, pp. 404–417.

Saijo, T. (2008). "Chapter 85 Spiteful Behavior in Voluntary Contribution Mechanism Experiments". *Handbook of Experimental Economics Results*. Vol. 1. Chap. 85, pp. 802–816.

Schotter, A. and I. Trevino (2014). "Belief Elicitation in the Laboratory". *Annual Review of Economics* 6, pp. 103–128.

Sefton, M. and R. Steinberg (1996). "Reward structures in public good experiments". *Journal of Public Economics* 61.2, pp. 263–287.

Sterner, T. (2015). "Higher costs of climate change". *Nature* 527, pp. 177–178.

Traeger, C. (2011). "Sustainability, limited substitutability, and non-constant social discount rates". *Journal of Environmental Economics and Management* 62.2, pp. 215–228.

Van Dijk, F., J. Sonnemans, and F. Van Winden (2002). "Social ties in a public good experiment". *Journal of Public Economics* 85.2, pp. 275–299.

Vesterlund, L. (2016). "Using experimental methods to understand why and how we give to charity". *Handbook of Experimental Economics*. Ed. by J. H. Kagel and A. E. Roth. Princeton University Press, pp. 1–74.

Willinger, M. and A. Ziegelmeyer (2001). "Strength of the Social Dilemma in a Public Goods Experiment: An Exploration of the Error Hypothesis". *Experimental Economics* 4.2, pp. 131–144.

Yamakawa, T, Y Okano, and T Saijo (2016). “Detecting motives for cooperation in public goods experiments”. *Experimental Economics* 19.2, pp. 500–512.