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Fair share and social efficiency: A mechanism in which peers decide on the payoff division ☆

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ABSTRACT

We propose and experimentally test a mechanism for a class of principal-agent problems in which agents can observe each others' efforts. In this mechanism each player costlessly assigns a share of the pie to each of the other players, after observing their contributions, and the final distribution is determined by these assignments. We show that efficiency can be achieved under this simple mechanism and, in a controlled laboratory experiment, we find that players reward others based on relative contributions in most cases and that the players' contributions improve substantially and almost immediately with 80 percent of players contributing fully.

1. Introduction

It can be difficult for a principal to observe individual agent's effort levels, particularly when agents work in teams. The extensive monitoring that would be required may not be feasible or cost-effective. Profit sharing has been suggested as a response (Weitzman and Kruse, 1990), since giving each of the agents a stake in an enterprise's profits does provide a link between agent contribution and agent reward that is missing from a fixed wage or salary structure. But under an equal sharing allocation, which is the natural allocation for a principal to impose when she cannot observe individual agent's behaviour, a free-rider problem arises since each agent bears the full cost of their contribution but only reaps $\frac{1}{N}$th of the benefit in an N-agent team. Unless the costs of contribution are low or the interdependencies between agent productivities in team production are high (Heywood and Jirjahn, 2009), agents will not contribute their social optimal contribution under an equal-sharing regime. If rewards are not related to contribution, an agent who feels under-compensated may end up reducing her contribution.

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Although the principal may be unable to observe agents' contributions, there will be occasions where the agents themselves are in a position to observe each others' actions.[1] The challenge then for the principal is to design a mechanism that elicits and uses this information to induce the appropriate levels of contribution from the agents. In this context, we consider a simple mechanism in which agents are not only able to monitor each other, but also in positions to determine each other's payoffs. The mechanism we propose takes the form of a two-stage game. In the first stage, each player chooses some contribution level and in the second stage, after having observed each others' contributions, each player proposes a fraction of the total surplus to be received by each of the remaining players. A player's final share depends on the other players' allocation toward her.

We label our mechanism the "Galbraith Mechanism" (GM hereafter) as the idea is inspired by John Kenneth Galbraith who, in an aside in *The Great Crash 1929*, described a bonus sharing scheme used by the National City Bank (now Citibank) in the U.S. in the 1920s. Under this scheme each officer would sign a ballot giving an estimated share of the bonus pool towards each of the other eligible officers, himself/herself excluded. The average of these shares would then guide the final allocation of the bonus to each of the officers (Galbraith, 1963, p. 171). This sharing mechanism can be applied to many economic problems including games with positive externalities and principal-agent problems in which the principal needs to distribute some common resource amongst the agents.[2]

The crucial feature of the GM is that how a player allocates shares in the second stage does not affect her own payoff. Therefore, players are able to reward or punish their peers based on the first stage observed actions. A number of studies have demonstrated that players exhibit social preferences to "punish" those who free-ride on the group production (Fehr and Gächter, 2000) and to "reward" those who contribute more than the group average (Sefton et al., 2007; Nosenzo and Sefton, 2012). While such social preferences move the outcome towards social efficiency, self-interest tends to restrict their application and the social costs that these punishments and rewards impose on all parties involved tend to limit their ultimate success (see Chaudhuri (2010) for a review).[3] The GM is based on an endogenous payoff allocation in which players can freely decide on some fraction of the co-players' payoffs. Players are free to punish, to reward, to allocate equally or even to allocate randomly to the remaining players, while no costs are incurred by any players in the allocation exercise.

The downside of allowing players the freedom to reward and punish in this way is a potential for multiplicity of Nash Equilibria at the second stage of the GM game. Without more structure, every allocation is a Nash Equilibrium in the second stage. One method of removing the resulting arbitrariness is by explicitly incorporating a behavioural component into the payoff function, which could be seen as reflecting the player's subjective notion of a "fair" allocation.[4] But rather than imposing a solution in this way, we leave the question of how the players actually allocate to be uncovered in the experiments that follow. That said, our investigation of equilibria in this contribution game does reveal a link between efficiency and "fairness". Much of the theoretical literature on fairness focuses on equality and equal share (e.g., Fehr and Schmidt, 1999) regardless of contributions. But a growing empirical literature appeals to other fairness criteria to justify unequal allocations, e.g., Adams (1965); Konow (1996; 2000; 2009); Gächter and Riedl (2006); Cappelen et al. (2007); Shaw (2013); Cappelen et al. (2013).[5] Prominent here is the notion of distributive justice first explored by sociologists (Homans, 1958; Adams, 1965) and later adopted by behavioural economists (Selten, 1978).

Distributive justice is often defined by the principle that a player's entitlement towards some group outcome should be proportional to her contribution to that outcome.[6] In the next section, we establish that such "fair" allocation behaviour can support efficiency (full contributions) as part of a SPNE of this contribution game, for all positive returns to total contributions. It is a pivotal case in that other more pro-contribution biased allocations (i.e. allocations that give disproportionately larger allocation shares to those with higher contribution shares) also support the efficient equilibrium under the same conditions, but anti-contribution biased allocations (i.e. allocations that give disproportionately larger allocation shares to those with lower contribution shares), such as equal shares, only support the efficient equilibrium at higher returns to total contributions. Proportional allocations feature prominently in our experimental results.

The GM is also "simpler" than other endogenous mechanisms proposed to solve social dilemma problems. For example, Andreoni and Varian (1999) studied a mechanism where players can agree on a pre-play contract before playing the prison-

[1] Freeman (2008) reports survey results showing: that most workers believe that they are able to detect shirking by co-workers; that those participating in a profit-sharing scheme are more likely to act against shirking; and that such anti-shirking behaviour tends to reduce shirking.

[2] A familiar example where our mechanism might be applied is the division of marks in university level group assignments. Professors typically observe only the final output but wish to award marks based on individual students' inputs. In such a situation, our mechanism can be described by a two stage game in which students choose how much to contribute in the first stage and in the second stage, after observing each others' contributions, each student proposes a fraction of the total marks (the sum of marks given to all students in the group) to be given to each of the remaining students in his group.

[3] The practicality of implementing "costly punishment" within organisations remains unclear (Nikiforakis, 2008).

[4] Konow (2000) adds a loss component to the player's utility function to capture the cognitive dissonance suffered whenever the player himself does not abide by the distributive justice principle towards other players.

[5] The literature distinguishes between two types of allocators: stakeholders and spectators. Stakeholders can allocate stakes to themselves in the allocation decisions and a self-biased fairness view may occur (Konow, 2000). Spectators allocate among the others and therefore, are more likely to maintain impartiality. Under the GM, all allocators are spectators because their allocation decisions do not affect their own shares.

[6] In one of Konow's (2000) experiment treatments, participants were divided into groups of two and were asked to fold envelopes as a task. A piece rate per envelope was paid to each group. A disinterested third party was then asked to divide each group's earnings between the group members. It was found that more than 90% of third parties allocated to each member a share that was proportional to the member's contribution, i.e., the number of envelopes they fold.

er's dilemma game. However, their mechanism does not perform well when tested in laboratory settings (Hamaguchi et al., 2003; Bracht et al., 2008). While there are other mechanisms that perform better in the laboratory, for example, Falkinger et al. (2000); Masuda et al. (2014) and Stoddard et al. (2014), they either add an enforcement institution, or "impose" an informed third party to allocate the shares. In the context of an uninformed principal and informed agents, the GM is a method of determining an informed allocation for the principal to make which requires only that the principal collate the allocation shares proposed by the players and distribute accordingly.[7] Provided the players are inclined to reward contribution in the second stage, and they anticipate this happening at the first stage, the GM should yield outcomes closer to social efficiency than an equal shares mechanism.[8]

Perhaps the model closest to ours is Baranski (2016) who considers a class of voluntary contribution mechanism in which the players' shares of the group fund are determined using a Baron and Ferejohn (1989) multilateral bargaining procedure in which each player can be randomly chosen to be a proposer at a certain period. In each period, after a division is proposed, the remaining players can vote to agree or disagree with the proposal. The bargaining process ends if a majority agree with the proposer and the fund is divided as per the proposal. The most important distinction between this mechanism and the GM lies in the allocation stage which takes the form of a one-shot game in the GM, whereas in Baranski's mechanism, it is given by a multi-stage bargaining process. Furthermore, the GM does not require a randomly chosen proposer as each player simply proposes a share for his peers. In terms of experiment results, both mechanisms enjoy a substantial increase in the contribution levels once they are introduced.[9]

In summary, the main contribution of this paper is to propose a simple mechanism and to test it experimentally. As noted, this mechanism: (i) allows costless reward and punishment at the allocation stage; (ii) removes the bias arising when a player proposes an allocation to himself; and (iii) avoids the necessity of imposing an informed allocator or randomly selecting one as part of a bargaining process. Only low returns to scale, where equal shares would not automatically generate full contributions, are considered. Provided players reward others based on their contributions at the allocation stage, and anticipate such rewards at the contribution stage, we expect that social efficiency can be achieved under this mechanism. This allocative behaviour does seem to be prevalent in the experiments reported below.

Our analysis provides five main findings. First, the GM produces a much higher average contribution level than equal sharing, for all returns to scale in the range considered. Second, under the GM the average contribution level is sensitive to the returns of scale and is higher when returns to scale are higher. Third, most allocations under the GM are related to players' contributions and the overall outcomes are consistent with players following a proportional allocation. Finally, players who receive allocations according to their relative contribution in the previous round increase their contributions in the next round. Relative to this, high (low) contributors last round tend to have lower (higher) contributions this round. But all tend to increase their contributions, except high contributors in the last round who were under-compensated at the allocation stage.

The remainder of the paper is organised as follows. Section 2 presents our mechanism and its assumptions. Section 3 describes the experimental design. Experimental results are discussed in section 4 and section 5 concludes.

2. Galbraith mechanism

2.1. The model

We consider the following principal-agent problem, with three agents (players) and one principal, in the context of a two-stage game. Each player, indexed i, has an initial endowment of $\bar{e} > 0$ and takes an action $e_i \in E_i = \{0, 1, .., \bar{e}\}$ in the first stage. The agents do so simultaneously. The players' actions determine a joint monetary outcome $\Pi = \beta \sum_{i=1}^{3} e_i$ which must be allocated among the players, where $\beta > 1$ is a parameter that represents the scale of returns of the production function. The allocation takes place in the second stage as follows. Each player i observes all actions taken in the first stage and proposes share a_{ij} of the outcome to each player $j \neq i$ such that

$$a_{ij} \in [0, 1] \text{ and } a_{ij} + a_{ik} = 1, \text{where } k \neq j \text{ and } k \neq i \tag{1}$$

In other words, each player proposes a fraction of Π to be received by each of the other players. They do so simultaneously. We let q_i denote player i's final share of the outcome Π and we assume that it is determined by: $q_i = \frac{a_{ji}+a_{ki}}{3}$. Finally, we let player i's payoff be given by $\pi_i = \bar{e} - e_i + q_i \Pi$. We call this mechanism the "Galbraith Mechanism" (GM).

The above can be seen as an instance of the principal-agent problem in which the principal is not able to monitor the contribution levels of the agents, who by contrast, can observe each others' contributions. The principal aims to design

[7] Early mechanism design and implementation literatures have focused on theoretical frameworks in environments in which there is uncertainty about the players's type and where the principal's main concern is in making the player reveal some information about his type (e.g., see Laffont, 1987). Chen (2008) provides a review of mechanisms tested in the laboratory.

[8] In practice, discriminatory preferences or collusion by subgroups of players could reduce the efficiency of the mechanism. These possibilities are excluded by players' anonymity and rotation between rounds in the experiments that we report below. Further discussions can be found in Dong (2017).

[9] Chen and Gazzale (2004) experimentally tested a family of compensation mechanisms with strategic complementarity and found that supermodularity can play an important role in demonstrating how learning in games leads to convergence to Nash Equilibrium.

a mechanism that can achieve efficiency by eliciting maximum contributions from the agents. We are interested in the conditions under which the GM achieves efficiency and whether these conditions are less stringent than those needed under the scenario where the principal allocates an equal share to each agent.[10] More precisely, we look for an equilibrium of the game, in which each player chooses $\bar{e}$ in the first stage.

2.2. Strategies and equilibrium in extensive-form

The game can be formally described as an extensive-form game, with simultaneous moves at each stage. For this class of games, Moore and Repullo (1988) gave a formulation of an extensive game that allows for simultaneous moves at the decision nodes. Under their formulation, at each node, all players know the entire history of the moves preceding it, and they can therefore use history-dependent strategies.[11] Following Moore and Repullo, we define a strategy of player i by the pair $s_i \equiv (e_i, a_i(e))$, where e_i is a contribution level of the player at his first information set and $a_i(e) \equiv \left(a_{ij}(e), a_{ik}(e)\right)$ is an allocation function that depends on the first stage contribution vector e and that satisfies (1). Thus, the allocation function prescribes an action to player i for each of her remaining information sets.[12] We then refer to triple $s = (s_1, s_2, s_3)$ as a strategy profile of the game.[13] We use the same definitions of Nash Equilibrium (NE) and Subgame Perfect Nash Equilibrium (SPNE) as in Moore and Repullo. Using their formulation of an extensive game, we can simply use backward induction to solve the game, starting with the last subgames, that is, the subgames starting in stage two, taking contribution vector e as given in each of those subgames.

It can easily be verified that every function $a(e) = (a_1(e), a_2(e), a_3(e))$ prescribes a Nash equilibrium in each stage two subgame. Then, by backward induction, it suffices to find the Nash Equilibrium of the resultant first stage game, by taking function $a(e)$ as given.[14,15] Then, $e^* \equiv (e_i^*, e_{-i}^*)$ is a Nash Equilibrium of the resultant first stage game if for all i and for all e_i, we have

$$\pi_i((e_i^*, e_{-i}^*), (a(e_i^*, e_{-i}^*))) \geq \pi_i((e_i, e_{-i}^*), (a(e_i, e_{-i}^*))) \tag{2}$$

It should be clear that the satisfaction of the above inequality, together with the fact that every allocation function $a(e)$ prescribes a Nash equilibrium in each second stage subgame, imply that s^* is a SPNE of the game, where

$$s^* = ((e_1^*, a_1(e)), (e_2^*, a_2(e)), (e_3^*, a_3(e)))$$

We are interested in allocation functions that support the full contribution vector $(\bar{e}, \bar{e}, \bar{e})$ as part of a SPNE.

2.3. General allocations

We can write player i's payoff function as

$$\pi_i((e_i, e_{-i}), a(e_i, e_{-i})) = q_i(e)\beta[e_1 + e_2 + e_3] + \bar{e} - e_i \tag{3}$$

where $q_i(e)$ is player i's allocation share (that he receives from the others). From (2), for full contributions to be part of a SPNE given some $a(e)$, the following must hold.[16]

$$3q_i(\bar{e})\beta\bar{e} + \bar{e} - \bar{e} \geq q_i(e_i, \bar{e}_{-i})\beta[e_i + 2\bar{e}] + \bar{e} - e_i \tag{4}$$

for all i and for all $e_i \in E_i = \{0, 1, ..., \bar{e}\}$. We split condition (4) into two cases:

(i) If $e_i = 0$, then (4) becomes

$$3q_i(\bar{e})\beta \geq 2q_i(0, \bar{e}_{-i})\beta + 1 \tag{4a}$$

[10] Our benchmark scenario is one in which there is imperfect information so that even agents cannot observe each other's contribution, and the principal uses an equal division allocation in this case.

[11] Note that Moore and Repullo (1988) study a related well-known class of implementation problems in which the principal tries to implement an efficient outcome, under an environment where the agents can be of different types (each type is defined by some preference relation). Our setting differs from theirs in that there is no uncertainty about the players' types and in our case, the principal is trying induce some action by the players, rather than making them reveal some information about their types.

[12] Note that since $a_i(e)$ is a function that maps from the set of all possible stage-one contribution vectors into the set of all possible allocation pairs to players j and k, it also prescribes allocations at the off-path subgames and thus, as required by the definition of a strategy in extensive-form, s_i prescribes some action at every information set of player i.

[13] An equivalent way of writing strategy profiles is adopted by Chen and Gazale (2004). Applying their definition to our context, a strategy profile would be given by a sextuple $((e_1, e_2, e_3), (a_1(e), a_2(e), a_3(e)))$.

[14] Again, observe that any function will work as all allocation functions are NE in all stage two subgames.

[15] Such an approach was used by Chen and Gazzale (2004) and by many others in the two-stage games literature.

[16] Note that $q_i(e)$ is uniquely determined by $a(e)$.

(ii) If $0 < e_i < \bar{e}$, then we can rewrite (4) as

$$\left[\beta \frac{q_i(\bar{e})}{c_i(\bar{e})} - 1\right] \bar{e} \geq \left[\beta \frac{q_i(e_i, \bar{e}_{-i})}{c_i(e_i, \bar{e}_{-i})} - 1\right] e_i \tag{4b}$$

where $c_i(e_i, e_{-i}) = \frac{e_i}{e_1+e_2+e_3}$ is player i's contribution share. For case (ii), let $R_i(e) \equiv \frac{q_i(e)}{c_i(e)}$ denote the ratio of the allocation share to the contribution share, which we call the Allocation Contribution Ratio (ACR) of player i.

We say that an allocation is *completely fair* if

$$q_i(e) = \begin{cases} \frac{1}{3} & \text{if } e = (0,0,0) \\ c_i(e) & \text{otherwise} \end{cases}$$

That is, each player receives an allocation share equal to his contribution share, except when there are no contributions when all players receive an equal share (of nothing). We can then show:

Proposition 1 *(Complete Fairness sufficient for Efficiency). If $\beta > 1$ and if there exists some allocation function $a'(e)$ such that the allocation to each player i is completely fair, then $s = ((\bar{e}, a'_1(e)), (\bar{e}, a'_2(e)), (\bar{e}, a'_3(e)))$ is an SPNE of the game.*

Proof. (i) if $e_i = 0$, then $q_i(0, \bar{e}_{-i}) = c_i(0, \bar{e}_{-i}) = 0$ and $q_i(\bar{e}) = c_i(\bar{e}) = \frac{1}{3}$. Substituting in (4a) we obtain $\beta\bar{e} \geq \bar{e}$, which is satisfied since $\beta > 1$. (ii) If $0 < e_i < \bar{e}$, (4b) becomes $[\beta - 1]\bar{e} \geq [\beta - 1]e_i$, which is also satisfied since $\beta > 1$. □

Thus, complete fairness in allocations implies that full contributions are part of a SPNE of the game.[17]

Unfortunately, it is not always possible to make the ACR equal to unity in the GM. For example, suppose that player i's contribution share is unity, then under the GM, the maximum allocation share that player i can obtain is $\frac{1+1}{3} < 1$. Fortunately, there are other allocations that deviate from complete fairness that can still achieve the efficient outcome.

Under a completely fair allocation, a player's allocation share adjusts in the same direction and in exactly the same proportion as any change in his contribution share, and Proposition 1 shows that this response in the allocation share is sufficient to discourage a player from reducing his contribution below the full contribution equilibrium. It therefore follows that allocations which adjust a player's allocation share in the same direction and more than proportionately to any change in his contribution share will also support this equilibrium. Relative to a completely fair allocation, these allocations have a "pro-contribution" bias (i.e. biased in favour of the largest contributions), and we give an example of this in the next sub-section.

What about allocations that are "anti-contribution" biased (i.e. biased in favour of the smallest contributions)? Can allocation behaviour which changes a player's allocation share less than proportionately to any change in his contribution share also support the full contribution equilibrium? We now use (4a) and (4b) to show that it can, but that the extent to which an anti-contribution biased allocation can support full contributions as part of a SPNE, depends on the returns to scale (β).

We assume that the allocation functions treat all the players in a *symmetric* way so that, for each contribution vector, changing the names of the individuals would not change their allocation.[18] In the context of the GM, one implication of the symmetry assumption is that two players who make the same contributions will receive the same allocation shares.

Consider first the case where $0 < e_i < \bar{e}$, then (4b) can be rewritten as $\{\beta R_i(\bar{e}) - 1\}\bar{e} \geq \{\beta R_i(e_i, \bar{e}_{-i}) - 1\}e_i$ which leads to

$$\{\beta R_i(\bar{e}) - 1\}[\bar{e} - e_i] \geq \beta[R_i(e_i, \bar{e}_{-i}) - R_i(\bar{e})]e_i \tag{5}$$

Since $R_i(\bar{e}) = 1$ as allocation shares are symmetric, we can, after some rearrangement, rewrite (5) as

$$\frac{\{\beta - 1\}}{\beta} \geq \frac{[R_i(e_i, \bar{e}_{-i}) - R_i(\bar{e})]}{\frac{[\bar{e} - e_i]}{e_i}} \tag{6b}$$

The RHS of (6b) is the ratio of the change in the ACR to the proportional change in the contribution. Since we are considering cases where $[R_i(e_i, \bar{e}_{-i}) - R_i(\bar{e})] > 0$, that is the allocation share to i falls by less than i's contribution share when i reduces his contribution, condition (6b) then puts an upper bound on the extent to which this can occur and still have full contributions as part of a SPNE. Note that this upper bound is increasing in β.

When $e_i = 0$, $c_i(0, \bar{e}_{-i}) = 0$ and $R_i(0, \bar{e}_{-i})$ is undefined. Our interest then is to what extent $q_i(0, \bar{e}_{-i})$ can exceed zero (i.e. player i receives a positive allocation share while making no contribution) while still supporting full contributions as part of a SPNE. Substituting $q_i(\bar{e}) = \frac{1}{3}$ in (4a) we obtain

[17] Furthermore, it is straightforward to show that complete fairness in allocations also rules out the equilibrium in which no player makes a positive contribution if $\beta > 1$.

[18] This symmetry condition is often referred to as anonymity in social choice theory (see Myerson, 2013).

$$\frac{\{\beta-1\}}{2\beta} \geq q_i(0, \bar{e}_{-i}) \tag{6a}$$

Together (6a) and (6b) show how far an allocation can be anti-contribution biased while still supporting full contributions as a part of a SPNE. Note that the left sides of both inequalities tend to zero as β tends to unity. The smaller is the returns to scale in production, the smaller the anti-contribution bias must be to support full contributions as part of a SPNE.[19]

2.4. Specific allocations under the GM

We can use the results of the previous subsection to determine the values of β for which any specific allocation behaviour can support full contributions as part of a SPNE. We are interested in allocation behaviour that provides this support as a part of SPNE, for the lowest possible values of beta. From the previous subsection we know we could achieve this by restricting our attention to allocations that are symmetric and pro-contributions. We first consider the benchmark case of equal division and compare it with two specific allocations ("winner takes all" and a proportional allocation), and a generalised proportional allocation that encompasses the others as special cases and later allows us to categorise the allocation behaviour of the experimental subjects.[20]

2.4.1. Equal shares

An egalitarian allocation is anti-contribution biased since a player's allocation share is unaffected by his contributions—i.e. $q_i(e) = \frac{1}{3}$ for all i. Then if $e_i = 0$, (6a) becomes $\frac{\{\beta-1\}}{2\beta} \geq \frac{1}{3}$ which is satisfied if and only if $\beta \geq 3$; while if $0 < e_i < \bar{e}$, then $R_i(e_i, \bar{e}_{-i}) - R_i(\bar{e}) = \frac{\frac{1}{3}}{\frac{e_i}{e_i+2\bar{e}}} - \frac{\frac{1}{3}}{\frac{1}{3}} = \frac{2}{3}\frac{(\bar{e}-e_i)}{e_i}$ and (6b) becomes $\frac{\{\beta-1\}}{\beta} \geq \frac{2}{3}$ which is also satisfied if and only if $\beta \geq 3$.

Only when $\beta \geq 3$, can we achieve an efficient outcome with equal shares. The potential benefits of the GM therefore arise when $\beta < 3$, and our results will be benchmarked against this case. In Appendix A.2 we show that zero contributions can be supported as part of a SPNE if $\beta < 3$.

2.4.2. Winner takes all

This is the extreme case of a pro-contributions biased allocation. We say player i follows "winner takes all" allocation behaviour if he allocates all to the highest contributor when the other players make unequal contributions and divides it equally between them otherwise—i.e.

$$a_{ij}(e) = \begin{cases} 1 & \text{if } e_j > e_k \\ \frac{1}{2} & \text{if } e_j = e_k \end{cases}$$

Then, if $e_i = 0$, $q_i(\bar{e}) = \frac{1}{3}$, $q_i(0, \bar{e}_{-i}) = 0$ and (4a) is satisfied for all $\beta > 1$. While if $0 < e_i < \bar{e}$, then $q_i(e_i, \bar{e}_{-i}) = 0$ and (4b) becomes $[\beta-1]\bar{e} \geq -e_i$, which is also satisfied as $\beta > 1$.

A winner-takes-all allocation supports full contributions as a SPNE for all $\beta > 1$. In Appendix A.2 we show that zero contributions can be supported as part of a SPNE under this allocation if $\beta \leq \frac{3}{2}$.

2.4.3. Proportional allocation

We say that player i follows *proportional allocation behaviour* if he allocates to the other players exactly according to their relative contributions—i.e.

$$a_{ij}(e) = \begin{cases} \frac{e_j}{e_j+e_k} & \text{if } e_j + e_k > 0 \\ \frac{1}{2} & \text{if } e_j + e_k = 0 \end{cases}$$

This corresponds to a fair allocation by player i to the other players in the game. We can now show the following:

Proposition 2. *Suppose that $\beta \geq \frac{6}{5}$, then $s = ((\bar{e}_1, a_1(e)), (\bar{e}_2, a_2(e)), (\bar{e}_3, a_3(e)))$ is a SPNE of the game, where function $a(e) = (a_1(e), a_2(e), a_3(e))$ satisfies proportional allocation behaviour.*

Proof. (i) If $e_i = 0$, then $q_i(0, \bar{e}_{-i}) = 0$ and (6a) is satisfied for all $\beta > 1$.
(ii) If $0 < e_i < \bar{e}$, then $q_i(e_i, \bar{e}_{-i}) = \frac{2}{3}\left\{\frac{e_i}{e_i+\bar{e}}\right\}$, $c_i(e_i, \bar{e}_{-i}) = \frac{e_i}{e_i+2\bar{e}}$, and $R_i(e_i, \bar{e}_{-i}) = \frac{2}{3}\left\{\frac{e_i+2\bar{e}}{e_i+\bar{e}}\right\}$.

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[19] Note that the results presented in this section readily generalize up to any finite number of players.

[20] The necessary and sufficient conditions for full contributions to be supported as a SPNE do not guarantee that this equilibrium is unique, however. To illustrate this for each allocation we also present the necessary and sufficient condition for zero contributions to be supported as a SPNE (see appendix A.2 for details).

Since $R_i(\bar{e}) = 1$, we have $R_i(e_i, \bar{e}_{-i}) - R_i(\bar{e}) = \frac{1}{3}\left\{\frac{\bar{e}-e_i}{e_i+\bar{e}}\right\}$. Substituting in (6b) we get

$$\frac{\{\beta - 1\}}{\beta} \geq \frac{1}{3}\left\{\frac{e_i}{e_i + \bar{e}}\right\} \tag{7}$$

Since the RHS of (7) is increasing in e_i, we get its upper limit by setting $e_i = \bar{e}$. This implies that condition (6b) is satisfied as long as

$$\frac{\{\beta - 1\}}{\beta} \geq \frac{1}{6} \text{ or } \beta \geq \frac{6}{5}. \quad \square$$

Thus, $\beta \geq \frac{6}{5}$ is necessary and sufficient for a proportional allocation to support full contributions as part of a SPNE.[21] However, in order to rule out zero contributions as part of any SPNE when the proportional allocation is used, we need the stringer condition that $\beta > \frac{3}{2}$, as for the winner takes all allocations (see Appendix A.2).

2.4.4. Generalised proportional allocation

Finally, we present a formula that encompasses a range of individual players allocations to others based on their contributions. For player i, let

$$t_{ij}(e) = \frac{1}{2} + \frac{\gamma}{2}\left[\frac{e_j - e_k}{e_j + e_k}\right]$$

We say that player i follows *generalised proportional allocation behaviour* if he allocates to other players as

$$a_{ij}(e) = \text{median}\{0, t_{ij}(e_j, e_k), 1\}$$

Note that $a_{ij}(e) = 1$ or $a_{ij}(e) = 0$ if $t_{ij}(e_j, e_k) \geq 1$ or $t_{ij}(e_j, e_k) \leq 0$, and $a_{ij}(e) = t_{ij}(e_j, e_k)$ otherwise. Here $\gamma \in [0, \infty)$ is a parameter whose magnitude measures player i's strength of concern for distributive justice. Two special cases illustrate this. First, if player i follows *egalitarian behaviour* and allocates an equal share to other players regardless of their contributions, then $\gamma = 0$ and $a_{ij}(e) = \frac{1}{2}$. Second, if player i follows *proportional behaviour* and allocates to the other players exactly according to their relative contributions, then $\gamma = 1$. Players for whom $0 < \gamma < 1$ make allocations that reflect a mixture of concerns for both equity and distributive justice. They under-compensate the larger contributor and over-compensate the smaller contributor, relative to the proportional allocation and are referred to as "sub-proportionists" below. Players for whom $\gamma > 1$ over-compensate the larger contributor and under-compensate the smaller contributor relative to the proportional allocation, and are referred to as "super-proportionists."[22] We now show

Proposition 3. *Suppose that $\beta \geq \max\{1, \frac{3}{1+\frac{3}{2}\gamma}\}$, then $s = ((\bar{e}_1, a_1(e)), (\bar{e}_2, a_2(e)), (\bar{e}_3, a_3(e)))$ is a SPNE of the game, where function $a(e) = (a_1(e), a_2(e), a_3(e))$ satisfies the generalised proportional allocation behaviour.*

Proof. See Appendix A.1 $\square$

Note that if all players are super-proportionists with $\gamma \geq \frac{4}{3}$ then full contributions are part of a SPNE for all $\beta \geq 1$, and that zero contributions can be supported as part of a SPNE if $\beta \leq \frac{3}{2}$ when $\gamma \geq 1$, and $\beta \leq \frac{3}{1+\gamma}$ otherwise (see Appendix A.2).

2.5. Section summary

We began this Section by describing the GM and then identified the conditions under which full contributions could be part of a SPNE of our contribution game. We found that an allocation that was completely fair (i.e. where the shares players are allocated are always equal to the shares they contributed) or was pro-contribution biased (i.e. where the allocation share adjusts in the same direction but more than proportionately with any change in contribution share) would support full contributions as part of a SPNE to the game for all $\beta > 1$. Allocations that are anti-contribution biased (i.e. where the allocation share adjusts in the same or opposite direction but less than proportionately with any change in contribution share) could also support full contributions as part of an equilibrium, but only at higher values of β. For example, the egalitarian allocation, in which allocation shares are completely divorced from contribution shares, can support full contributions as a SPNE, but only if $\beta \geq 3$.

[21] Note that this result generalizes to the n-player case. Following the same approach as in Proposition 2 we find that a necessary and sufficient condition for a proportional allocation to support full contributions is that $\beta \geq \frac{n(n-1)}{n(n-1)-1}$. The necessary and sufficient condition for a proportional allocation to support zero contributions is that $\beta \leq \frac{n}{n-1}$. See Appendix A.3.

[22] For very large values of γ player i's allocation will approximate that of rewarding only the higher contributor.

Table 1
Experiment Design.

Sessions	Treatment		β	Matching Protocol	No. of subjects	Indep. Groups
	Round1-10	Round11-20				
Control	Equal Share	Equal Share	1.8	Random	36	4
T0	Equal Share	GM1.8	1.8	Random	90	10
T1	Equal Share	GM1.2	1.2	Random	90	10
Total:					216	24

Clearly the ability of the GM to support an efficient equilibrium depends crucially on the allocation behaviour of the players. We have shown that every allocation function is a NE in all subgames of the second stage, but only some allocations will support the efficient equilibrium, depending on β. Whether the players will select such allocations is an empirical question which we attempt to answer through our experimental results in the next section.

3. Experimental design and procedure

Our experiments attempt to answer the following two questions: first, how do people allocate in the second stage; and second, how do people contribute in the first stage? Since our results indicate that the success of the GM in implementing full contributions is likely to be sensitive to the scale of returns on the production function (β), we run two sets of experiments under the GM. Those labelled GM1.8 set $\beta = 1.8$, which is above the threshold for a proportional allocation to support full contributions as part of a SPNE, and also above the threshold for zero contributions to be supported as part of a SPNE. Those labelled GM1.2 set $\beta = 1.2$ which is exactly on the threshold for a proportional allocation to support full contributions as part of a SPNE, and below the threshold for zero contributions to be supported as part of a SPNE. These features lead us to expect greater success for the GM when $\beta = 1.8$.

We ran 24 experimental sessions at the Centre for Decision Research and Experimental Economics (CeDEx) in Nottingham in February 2015. In total, 216 university students from various fields of study took part, with 9 participants in each session. Participants were allowed to participate in only one session. Those participants were drawn from the CeDEx subject pool, which was managed using the Online Recruitment System for Economic Experiments (ORSEE; Greiner, 2015). The experiment was programmed in z-Tree (Fischbacher, 2007). Each session lasted about 60 minutes and the average payment was £8.34 (equivalent to \$12.93 or €11.65 at the time of the experiment).

Upon arrival, participants were asked to randomly draw a number from a bag and they were seated in a partitioned computer terminal according to that number. The experimental instructions were provided to each participant in written form and were read aloud to the subjects (the instructions can be found in Appendix B). The experiment only started after all participants had given the correct quiz answers with respect to the instructions. The experiments have three treatments: one control treatment and two GM treatments.[23] Each experiment contained 20 rounds of decision making tasks that can be divided into two segments of ten rounds (see Table 1). The instructions for the second ten-round segment were distributed only after the completion of the first ten rounds. In each round, the computer program draws three participants to form a group, and the group composition reshuffles every round.[24]

Equal sharing allocations were applied to all participants in the first ten rounds.[25] We used neutral terminology in the experiment and the contribution question formulated on the computer screen was "Tokens you want to add to the Group Fund:__." In each round, each player i chose an integer from 0 to 10, which represented her contribution, e_i. The production function was $\Pi(e_1, e_2, e_3) = \beta(e_1 + e_2 + e_3)$, and each player's earning was $10 - e_i + \frac{1}{3}\Pi$. Two alternative values of β are considered. In sessions Control and T0, β equals 1.8, and in sessions T1, β equals 1.2.[26] At the end of each round, players were informed about all group members' contributions and payoffs and were reminded that they would not be in the same group again.

In rounds 11-20, there were two decision stages in each round of the GM. The first stage decision was the same as in the Equal Share treatment, that is, each player voluntarily chose an integer from 0 to 10. In the second stage, the computer screen displayed each group members' contribution decision in the first stage and the value of the group fund. Each player was then asked to divide $\frac{1}{3}\Pi$ between the other two group members with a resolution of 0.1. In other words, player i

[23] We had 10 sessions each of the GM but only 4 sessions of the Control treatment because previous studies strongly and robustly predict that equal share produces a low contribution rate (Ledyard, 1995). This conclusion was also supported by all four sessions of the control treatments.

[24] The matching of the three-person group was pre-determined by the computer software. Specifically, each participant would never be in the same group with the two other participants twice during the whole experiment. We randomized the display of players' contribution details on the screen in each round; in this way players were not able to track the identities of other players across rounds.

[25] The equal sharing allocation, where the final production is equally divided among group members, is equivalent to the voluntary contribution mechanism. To compare with other studies (e.g., Andreoni and Varian (1999); Fehr and Gächter (2000); Falkinger et al. (2000)), we introduce our mechanism after ten rounds of the equal sharing allocation.

[26] In session T1, β equals 1.2 in all rounds to minimize the variable changes during the experiment. As will be shown in section 4.1, the first ten rounds of all three treatments yield very similar results.

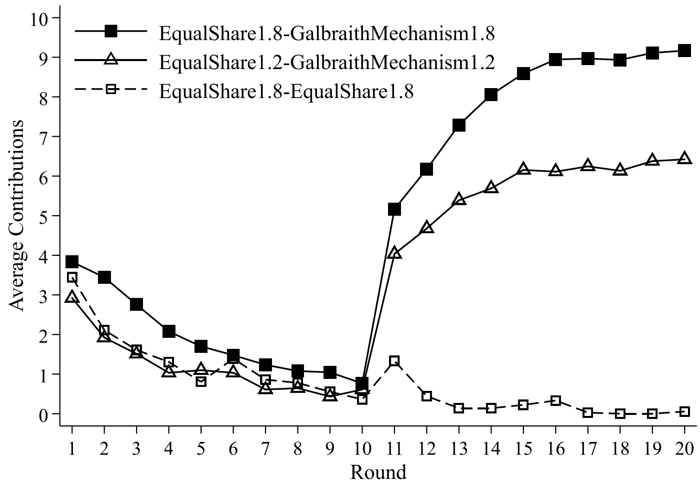

Fig. 1. Time-path of the Average Contribution by Treatment.

allocated $\tilde{a}_{ij}$ to player j and allocated the remaining $\tilde{a}_{ik} = \frac{\Pi}{3} - \tilde{a}_{ij}$ to player k.[27] Player i's share of the group production was determined by the allocation decisions by player j and player k. Her payoff function was $\pi_i = 10 - e_i + \tilde{a}_{ji} + \tilde{a}_{ki}$. In the control treatment, players simply repeated the same decision task as in rounds 1-10 for another ten rounds.

4. Experimental results

We split the analysis into three parts. Section 4.1 looks at the difference in the contribution decisions across treatments. Section 4.2 analyses the participants' allocation decisions, and Section 4.3 studies how allocation choices affect the players' contribution decisions.

4.1. Contributions

Fig. 1 displays the time-path of the average contributions over all 20 iterations for each treatment. In the first ten rounds, when the equal sharing allocation is used, we observe a steady decline in the level of contributions over time. Participants start with an average contribution level of 3.32 (3.72 if β equals 1.8 and 2.92 if β equals 1.2) and end up with 0.63 in round 10 (0.65 if β equals 1.8 and 0.61 if β equals 1.2). The average contribution levels do not differ across treatments ($p > 0.1$). This finding is consistent with results from other studies in which group compositions are reshuffled every round (e.g., Croson, 1996; Fischbacher and Gächter, 2010).

At the beginning of round 11, we introduce the GM in 20 out of 24 sessions. This introduction triggers a dramatic increase in the contribution level. Specifically, in round 11, the contribution level in both the GM1.8 (mean = 5.17) and the GM1.2 (mean = 4.03) are significantly higher than the contribution in the control treatment (mean = 1.33, Mann-Whitney test, $p < 0.01$).[28] Over the ten rounds of the GM1.8, the average contribution is 8.0 and the final round contributions reach an average of 9.16. Indeed, in round 20, most players (82.8%) in the GM1.8 contribute fully to the group fund, and 21 out of 30 three-player groups coordinate on the (10,10,10) equilibrium. Compared to the GM1.8, the average contribution in the GM1.2 (mean=5.72) is relatively lower ($p < 0.05$). Specifically, in the last round of the GM1.2, the average contribution is 6.42; 38.9% of the players contribute fully and 7 out of 30 groups coordinate on the (10,10,10) equilibrium. But there are also 11.1% of the players contributing zero and 1 of the 30 groups coordinates on the (0,0,0) equilibrium. On the other hand, almost all players (35 out of 36) in the control treatment have zero contribution in later rounds. In summary, the GM mechanism produces an initial jump that is further improved in subsequent rounds. Appendix C1 shows more comparative statistics of the contribution decisions across sessions and treatments.

Result 1. *Both the GM1.8 and the GM1.2 produce a much higher average contribution level compared to the control treatment, particularly in later rounds. The average contributions in the GM1.2 are lower than those in the GM1.8, consistent with our expectations. But even with the lower β value, we observe that the GM has greatly improved the contribution rate relative to equal sharing.*

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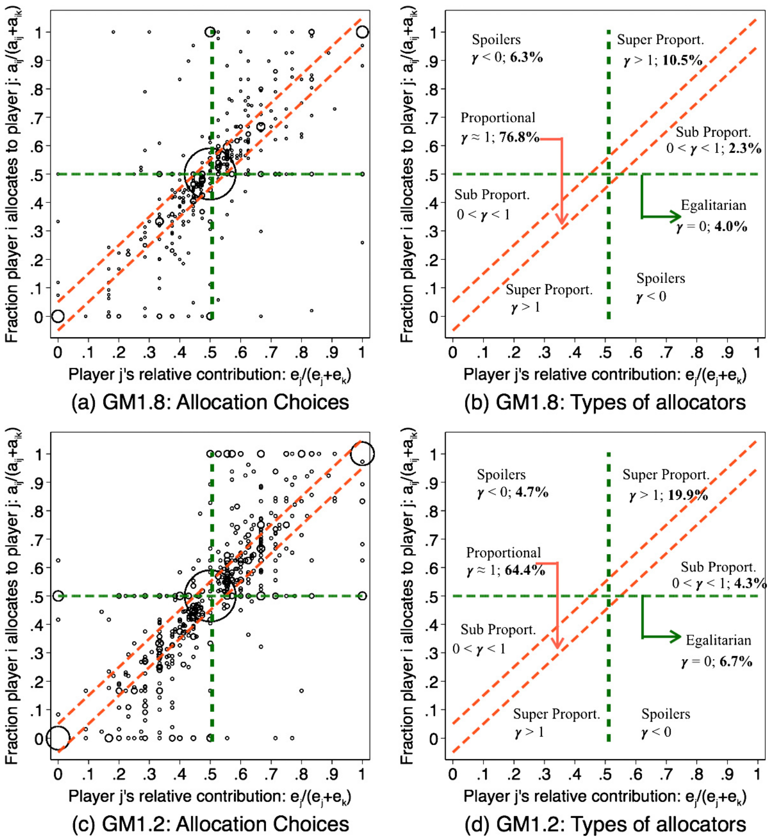
[27] In section 2, a_{ij} is defined as the proportion player i allocates to player j, and $a_{ij} + a_{ik} = 1$. To calculate player's final profit, a_{ij} would be normalized by dividing by the group number and multiplying by the joint profit, i.e., $\pi_i = 10 - e_i + \frac{a_{ji}+a_{ki}}{3}\Pi$. To make our experiment cognitively easy, we asked participants to divide $\frac{\Pi}{3}$ ex ante. In other words, we set $\tilde{a}_{ij} = \frac{\Pi}{3}a_{ij}$. We also conducted additional sessions where participants directly allocate one between the other two group members, as presented in section 2, and find no significant difference in contribution between both frames ($p > 0.1$).

[28] Because the Mann-Whitney test requires independent observations, the tests are conducted on sessions' average contribution level. The two-sided p values are reported.



Notes: Fig. 2(a) and Fig. 2(c) includes 900 allocation decisions each from the GM1.8 and the GM1.2 respectively. The size of the circle indicates the relative frequency of the observation. Observations lying on the 45-degree line means player i allocate proportionally according to others' relative contributions.

Fig. 2. Allocation Decisions in the Galbraith Mechanism.

4.2. Allocation decisions

In this section, we investigate players' allocation decisions. Recall that for each round in the GM treatment, participants need to decide on how to allocate between the other two group members. The allocation must sum up to one third of the group fund, that is, $\tilde{a}_{ij} + \tilde{a}_{ik} \equiv \frac{\Pi}{3}$. In the following analysis, we only consider each player i's allocation to player j (randomly determined from the data), $\tilde{a}_{ij}$, because the allocation to each player k is automatically determined by $\tilde{a}_{ik} \equiv \frac{\Pi}{3} - \tilde{a}_{ij}$. We represent players' allocation choices from the GM1.8 and GM1.2 in Fig. 2a and Fig. 2c, respectively. The horizontal axis indicates the fraction player j contributes relative to player k, that is, $\frac{e_j}{e_j+e_k}$, and the vertical axis shows the actual fraction i allocates to player j, that is, $\frac{\tilde{a}_{ij}}{\tilde{a}_{ij}+\tilde{a}_{ik}}$. The size of the circle indicates the relative frequency of the observation. Around 55.4% of the observations in the GM1.8 and 41.7% in the GM1.2 fall exactly on the 45-degree line where $\frac{e_j}{e_j+e_k} = \frac{\tilde{a}_{ij}}{\tilde{a}_{ij}+\tilde{a}_{ik}}$. This means a large number of players allocate proportionally according to the others' relative contributions.

Table 2 presents the results of further investigation of contributions using random effects regressions. In these regressions the dependent variable is the fraction player i allocates to player j, and the independent variable is the contribution of j relative to k. Allocating proportionally means the coefficient of $\frac{e_j}{e_j+e_k}$ equals 1 and the intercept term equals zero, and the estimates of these parameters in both regressions are consistent with this prediction. For both the GM1.8 and the GM1.2, the estimated coefficients (0.919 and 0.933, respectively), are different from zero ($p < 0.01$) and not significantly different from one (F-test, $p > 0.1$). The intercept, meaning the fraction player i allocates to player j when player j contributes zero, is not significantly different from zero ($p > 0.1$).

But even a casual look at the spread of observations in Fig. 2a and Fig. 2c suggests that *not all* players in fact allocate proportionally. Not all observations are gathered about the 45-degree line. In particular, there appears to be some clustering of observations above this line when $\frac{e_j}{e_j+e_k} > \frac{1}{2}$, and a corresponding clustering below this line when $\frac{e_j}{e_j+e_k} < \frac{1}{2}$, in both cases. After further inspection we find that we can categorise allocators into five different types as follows.

Table 2
Allocation Choice: Random Effects.

	Dep. Variable: Fraction Player i Allocate to Player j: $\frac{a_{ij}}{a_{ij}+a_{ik}}$			
	(1)	(2)	(3)	(4)
Player j's relative contribution $\frac{e_j}{e_j+e_k}$: β_1	0.917*** (0.067)	0.933*** (0.056)	0.917*** (0.067)	0.933*** (0.056)
Constant: β_0	0.044 (0.036)	0.034 (0.029)	0.045 (0.039)	0.034 (0.030)
#Data Used	GM1.8	GM1.2	GM1.8	GM1.2
#Data Exclusions	No	No	Yes	Yes
#Observations	900	900	466	648
#Clusters	10	10	10	10
$H_0: \beta_1 = 1$	1.53 ($p = 0.216$)	1.43 ($p = 0.232$)	1.51 ($p = 0.219$)	1.42 ($p = 0.234$)

Notes: (1) The table reports the regression results for random-effects model with the standard error clustered at the session level. *** indicates significance at 1% level. (2) Column 3 and 4 exclude the observations where we cannot distinguish whether player i is a proportionist or an egalitarian. (3) The results remain virtually unchanged if we control period dummies (see Appendix C.1.). (4) We report the test statistics for the hypotheses tests and 2-sided p values are in the brackets. (5) Hausman tests for random vs fixed effects model for all regressions yield p values greater than 0.1.

Proportionists ($\gamma = 1$) are the players who allocate strictly according to other's relative contributions, that is, $\frac{\tilde{a}_{ij}}{\tilde{a}_{ij}+\tilde{a}_{ik}} = \frac{e_j}{e_j+e_k}$. Because our software only allows the input with a resolution of 0.1 and $\frac{e_j}{e_j+e_k}$ may not always be a fraction of ten, we define player i as a Proportionist if $\left| \frac{\tilde{a}_{ij}}{\tilde{a}_{ij}+\tilde{a}_{ik}} - \frac{e_j}{e_j+e_k} \right| \leq 0.05$ (see the category highlighted as Proportionists in Fig. 2b and 2d). In most situations (76.8% in the GM1.8 and 64.4% in the GM1.2), players allocate like proportionists.[29]

Egalitarians ($\gamma = 0$) are the players who allocate equally to the other two group members regardless of their contributions. In 52.2% of the observations from the GM1.8 and 34.7% from the GM1.2, players allocate equally between the other two group members (see the category highlighted as Egalitarians in Fig. 2b and 2d). Note that proportionists and egalitarians are not mutually exclusive. For example, if the other two players contribute the same amount, both the proportional and the egalitarian allocations predict an equal allocation. This is not a rare case especially in later rounds (rounds 16-20), where full contributions of all three players are frequently observed. In total, there are 48.2% (GM1.8) and 28.0% (GM1.2) of the observations that can be classified under both proportional and egalitarian allocation behaviours. However, when conditioning on the inequality of contributions between the other two players, less than 10% of players choose to allocate equally.

Super-proportionists ($\gamma > 1$). If player j contributes less than player k, player i, under the "super-proportionists" category, rewards player j with less than what a proportionist would give. The other player, player k, is consequently over-compensated. 10.5% (GM1.8) and 19.9% (GM1.2) of the observations fall under this allocation behaviour (see the category highlighted as super-proportionists in Fig. 2b and 2d).[30] In other words, super-proportionists tend to "punish" the player who has a lower relative contribution and "reward" the player who has a higher relative contribution. Note that the punishment possibility in the GM is different from the "punishment mechanism" in Fehr and Gächter (2000). In their setting, players can choose to incur a cost to destroy part of the other players' payoff. With the GM, however, players bear no cost to punish others. Moreover, if a super-proportionist punishes one player, the other group member will be over-compensated automatically. Hence, the overall welfare remains unchanged.

Sub-proportionists ($1 > \gamma > 0$). If player j contributes less than player k, then a "sub-proportionist", rewards player j with more than what a proportionist would give. The other player, player k, is consequently under-compensated relative to a proportional allocation. 6.3% (GM1.8) and 5.8% (GM1.2) of the observations fall in this category (see the category labelled as Sub Proport in Fig. 2b and 2d).[31] While a sub-proportionist does award the larger contributor a larger share, it is less than proportional to their relative contribution.

[29] We also checked the relationship between the difficulty of calculating the contribution proportions and the adoption of the proportional allocation. Specifically, we classify each allocation decision as easy, medium, or difficult in terms of calculation. We found that the adoption of the proportional allocation does not differ across calculation difficulty levels.

[30] Note that unequal contributions is a necessary condition for an allocation to be classified as super-proportional. When contributions are equal, super-proportionists cannot be distinguished from proportionists or egalitarians. In the GM1.8, 51.8% of the allocation decisions are unequal while in the GM1.2, 72.0% of them are unequal. If we only count the unequal contributions, 21.9% of the allocation decisions in the GM1.8 and 28.6% in the GM1.2 can be classified as super-proportional.

[31] Again unequal contributions is a necessary condition for an allocation to be classified as sub-proportional. When contributions are equal, sub-proportionists cannot be distinguished from super-proportionists, proportionists or egalitarians. If we only count the unequal contributions, 6.9% of the allocation decisions in the GM1.8 and 8.1% in the GM1.2 can be classified as sub-proportional.

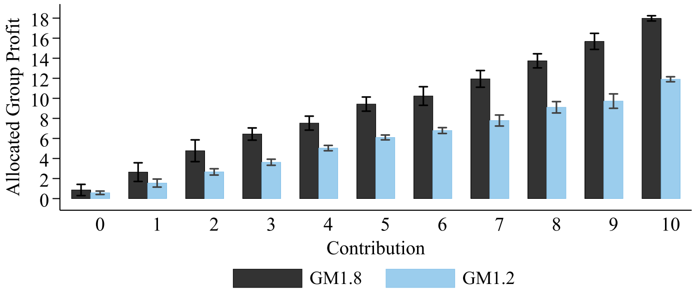


Fig. 3. Contribution and Average Profit Allocated to the Player (by the other two group members).

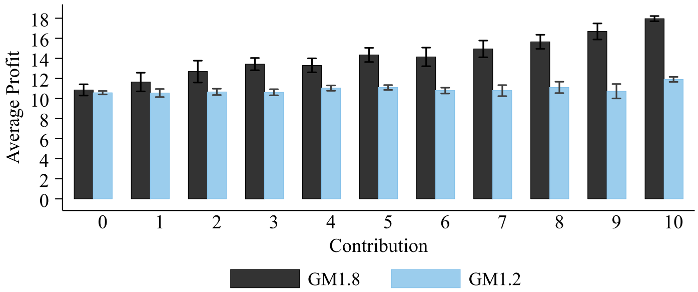


Fig. 4. Contribution and Average Profit.

Spoilers ($\gamma < 0$). The remaining 6.3% (GM1.8) and 4.7% (GM1.2) of observations that cannot be captured by any of the four allocation behaviours listed above, we label as "spoilers" (see Fig. 2b and 2d). Spoilers allocate a larger share to the lower contributor, providing a disincentive for contributions and making an efficient outcome less likely. Fortunately such anti-social behaviour is relatively rare.[32]

Result 2. *Most allocations are related to players' contributions and the overall outcomes are consistent with players following the proportional allocation behaviour. Based on the observations where contributions are unequal we conclude that in GM1.8 (GM1.2) 55.2% (50.6%) of players are Proportionists; 20.4% (27.6%) are Super-Proportionists; 7.7% (9.3%) are Egalitarians; 4.5% (6.0%) are Sub-Proportionists. There are also 6.3% (GM1.8) and 4.7% (GM1.2) Spoilers among all observations.*

The prevalence of the proportional allocation implies that relatively higher contributors would be rewarded with a relatively higher share of the group production. This is confirmed in Fig. 3 where we observe a clear positive relationship between players' contributions and their allocations from the group production. Fig. 4 depicts the relationship between players' contribution and their average final profit (i.e., their allocation from group production plus uncontributed endowment): the positive correlation still exists for the GM1.8 but is no longer there for the GM1.2. Higher contributors have higher total earnings in the GM1.8. But there is no obvious relationship, positive or negative, between contributions and total earnings in the GM1.2. This may at least partially explain the lower average contributions and greater diversity of session outcomes in the GM1.2.

4.3. Allocation received and contribution decisions

So far, we have established that most players do allocate according to others' relative contributions and the contribution rate is high. In this subsection, we check the causal relationship between these two events. Specifically, we look at the effect of the allocation players received in the previous round on their contribution decisions in the current round. Note that the allocation a player receives in a certain round is the aggregate result of her two group members' allocation behaviours, and we categorise these as in the previous section.[33] Most players are treated by the proportional allocation under most circumstances (77.5% in the GM1.8 and 67.7% in the GM1.2), and in many cases all three group members are rewarded with

[32] A deeper investigation of which players use the non-proportional allocation behaviours is provided by probit regressions in Appendix C2. For these players, the higher their contribution the more likely they are to be super-proportionists and the less likely to be egalitarians or sub-proportionists.

[33] The share player i should receive according to the proportional allocation is $q_i^p = \frac{1}{3}(\frac{e_i}{e_i+e_j} + \frac{e_i}{e_i+e_k})$. When $e_i + e_j = 0$ or $e_i + e_k = 0$, $q_i^p = \frac{1}{6}$ and when $e_i + e_j + e_k = 0$, $q_i^p = \frac{1}{3}$. The actual fraction player i receives is $q_i = \frac{a_{ji}+a_{ki}}{3}$. Player i is treated by the proportional allocation if $|q_i - q_i^p| \leq 0.05$. Relative to this, player i is over-compensated if $q_i > q_i^p + 0.05$ and under-compensated if $q_i < q_i^p - 0.05$. Since $q_i^p > \frac{1}{3}$ (or $< \frac{1}{3}$) as $e_i > \sqrt{e_j e_k}$ (or $< \sqrt{e_j e_k}$), we treat i as high (H) (low, L) contributor if i's contribution is higher (lower) than the geometric mean of the contributions of the other two players in this group.

Table 3
Determinants of One-Round Contribution Change.

Dependent Variable:	One-round Change in Contribution		
	(1)	(2)	(3)
Over-compensated High contributor	-0.152	-0.124	0.216
	(0.109)	(0.0810)	(0.270)
Over-compensated Low contributor	0.405**	0.492**	0.518
	(0.204)	(0.241)	(0.527)
Under-compensated High contributor	-1.386***	-1.355***	-1.521**
	(0.232)	(0.220)	(0.418)
Under-compensated Low contributor	0.795**	0.983***	3.116***
	(0.290)	(0.240)	(0.770)
Others' average contribution	0.0934***	0.0785***	0.333**
	(0.0179)	(0.0163)	(0.111)
The GM1.2 Treatment	0.0297	0.0346	0.0356
	(0.0828)	(0.0881)	(0.342)
Round	-0.155***	-0.159***	
	(0.0383)	(0.0288)	
Constant	2.244***	2.347***	-0.636
	(0.568)	(0.423)	(0.617)
Round used	12-20	12-20	12
Data Excluded	Yes	No	No
Clusters	20	20	20
Observations	1158	1620	180

Notes: (1) Column 1 and 2 reports the regression results for random-effects model. Column 3 uses the OLS regression. The standard errors are all clustered at the session level. *, ** and *** indicates significance level at the 10%, 5% and 1% levels, respectively. (2) Column 1 excludes observations where all three players contribute equally.

equal shares (47.7% in the GM1.8 and 30.2% in the GM1.2). Note that, in 45% of the total observations in the GM1.8 and 25.7% in the GM1.2, these two allocation behaviours overlap because all three players contribute equally.

We use random-effect regression to investigate the relationship. Our behavioural equation of the change in contribution for player i in round r, $\Delta e_{i,r}(\equiv e_{i,r} - e_{i,r-1})$ is given by:

$$\Delta e_{i,r} = \kappa_0 + \mathbf{B_{i,r-1}}\theta + \kappa_1 OtherContribution_{i,r-1} + \kappa_2 GM1.2 + \kappa_3 Round_i + \varepsilon_{i,r}$$

where $\mathbf{B_{i,r-1}}$ is a vector of dummy variables which indicate how the player was treated at the allocation stage in the previous round. Recall that a super-proportional allocation over-compensates the high contributor and under-compensates the low contributor, while the egalitarian, sub-proportional and spoiler allocations do the opposite—i.e., they over-compensate the low contributor and undercompensate the high contributor. We use these features to define our allocation dummies. Specifically, $B^{OCH}_{i,r-1}$ and $B^{UCL}_{i,r-1}$ are dummy variables indicating whether player i was an over-compensated high contributor or an under-compensated low contributor in round $r-1$, as if under a super-proportional allocation; while $B^{OCL}_{i,r-1}$ and $B^{UCH}_{i,r-1}$ indicate whether i was an over-compensated low contributor or an under-compensated high contributor in round $r-1$, as if under an egalitarian, sub-proportional or spoiler allocation. These are all measured relative to the proportional allocation which is taken as the base case. The variable $OtherContribution_{i,r-1}$ represents the average contribution of the other two members in the player's group in the previous round. This is intended as a proxy for the player's belief about the likely contributions of the other group members in the current round. The behavioural regulation of conditional cooperation (i.e. matching the other group members' contributions) is well documented in the literature (e.g. Fischbacher et al., 2001; Fischbacher and Gächter, 2010). $GM1.2$ equals 1 if the player belongs to the treatment GM1.2, $Round_i$ captures the time trend and $\varepsilon_{i,r}$ is an unobservable variable that is assumed to have mean zero and is uncorrelated with other explanatory variables.

In Table 3, we present two random-effects regressions with robust standard errors clustered at the session level, one with (column 1) and one without (column 2) data on the "overlap" observations (i.e., those where all players contribute equally), and one ordinary least square regression (column 3) focusing only at round 12. We discuss the random effects regressions first. Under our assumptions the estimated constants show that players who were treated proportionally in the previous round are likely to increase their contributions in the current round. Turning to the estimated coefficients on the allocation-treatment variables, it is clear that it is not whether a player is under- or over-compensated that determines the direction of change of their contributions, relative to a proportional allocation, but whether they were the high or low contributor. A high contributor has a lower increase in contribution (relative to those that received proportional treatment)

Thus player i's treatment is over-compensated high contributor (or OCH) when $q_i > q_i^p + 0.05$ and $e_i > \sqrt{e_j e_k}$; OCL when $q_i > q_i^p + 0.05$ and $e_i < \sqrt{e_j e_k}$; UCH when $q_i < q_i^p - 0.05$ and $e_i > \sqrt{e_j e_k}$; and UCL when $q_i < q_i^p - 0.05$ and $e_i < \sqrt{e_j e_k}$.

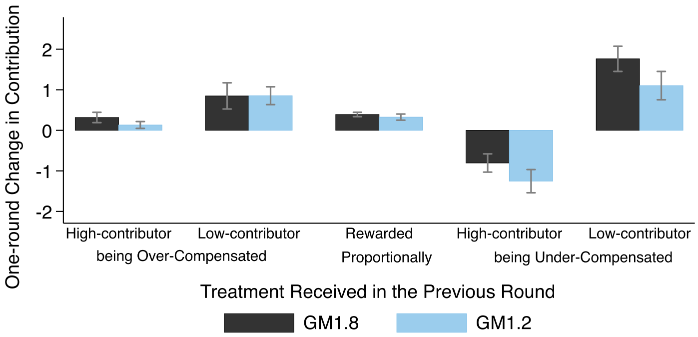


Fig. 5. Allocation treatment received in the previous round and player's one-round change in contribution.

regardless of whether he was over- or under-compensated, though the difference is not statistically significant for the over-compensated. Likewise the low contributor increases his contribution (relative to those that received proportional treatment) regardless of whether he was over or compensated. In terms of the magnitudes of the coefficients, those on the under-compensated variables are larger than those on the corresponding over-compensated variables, which suggests that the "punishment" rather than the "reward" aspect inherent in these allocations that is more effective in influencing contributions.[34] We also find no difference between the treatments in the change in contributions of those subject to a proportional allocation as the estimated coefficients on GM1.2 are not significantly different from zero. These results are largely unaffected by the inclusion of the overlap observations in column 2.

The estimated coefficient on *OtherContribution* is consistently positive and significantly different from zero indicating that a higher average contribution by the other group members in the previous round generates an increase in a player's contribution in the current round. Likewise, the negative coefficient on Round indicates that the increase in contributions get smaller as the rounds progress, other things equal. This is consistent with the concavity of the plots of the contributions in Fig. 1.

Fig. 5 relates the average change in contribution to the allocation treatment received in the previous round. These results are consistent with those from the regression analysis. The ranking of those whose contributions increase (in absolute value) are as follows, first, the under-compensated low contributors, then the over-compensated low contributors, followed by those subject to a proportional allocation, and finally the over-compensated high contributors. The under-compensated high players in fact reduce their contributions. The changes are approximately the same or smaller in the GM1.2 as the GM1.8 regime, which is consistent with the differences in the paths of the contributions under the two regimes in Fig. 1.

Finally, the last column reports the results based on observations from round 12 only, which is the first round in which the players receive feedback on the allocation made by the other group members. The average changes in the contributions of players who were over-compensated or treated to a proportional allocation in Round 11 are positive and not significantly different. A low contributor responds significantly positively and a high contributor responds significantly negatively to being under-compensated in Round 11, just as they do in later rounds. But noteworthy here is the magnitude of the estimated response of the under-compensated low contributors who increase their contributions by an average of 3.1 in Round 12 ($p < 0.001$). Based on the results in columns 1 and 2 we conclude:

Result 3. *How players are treated in the allocation stage affects their contribution decisions in the subsequent round. Those players who are treated by a proportional allocation tend to increase their contributions. Relative to this, high contributors last round tend to have lower contributions this round, and low contributors last round tend to have higher contributions this round. But all tend to increase their contributions, except high contributors in the last round who were under-compensated at the allocation stage.*

5. Conclusion

Our goal in this study was to propose and experimentally test a simple mechanism in which peers decide on others' payoffs after a joint production stage. While this mechanism does not involve bargaining, each player is able to propose an allocation to each of the remaining players. We tested the mechanism in an economic laboratory with groups of three players under two regimes differing in the scale of returns of the production function, and found that the majority of participants allocated according to other players' relative contributions in both regimes. Consequently, we observed average levels of contribution in both regimes much higher than those occurring under an equal sharing regime, and almost full contribution in the production stage in the later rounds of the experiment in the regime with the higher scale of returns. We interpret our result as a successful attempt to improve social efficiency by combining social preference with the right form of institution.

[34] Previous studies also find that the effect of punishment is stronger than the effect of reward (e.g., Andreoni et al., 2003; Sefton et al., 2007).

The pursuit of self-interest is an important assumption in the traditional mechanism design literature, as elsewhere in Economics. Because the GM permits players no role in determining their own share of the surplus at the allocation stage, they are free to allocate shares to other players. Thus even purely self-interested players may make proportional or pro-contribution biased allocations, particularly if they believe that other players will anticipate such behaviour and make full contributions leading to the socially optimal outcome. But of course players need not have this belief and need not allocate on this basis. Recent behavioural and experimental studies find evidence of various degree of "other-regarding" preferences (e.g., Fehr and Schmidt, 1999; Charness and Rabin, 2002; Cox et al., 2007; Benabou and Tirole, 2011). Although not intended as a replacement of pure self-interest, richer behavioural assumptions such as fairness and other moral standards can be valuable in the design of effective institutions. In our study, we demonstrate that a willingness to allocate on the basis of relative contributions, when utilized in an appropriate social institution (the GM), has significant advantages in overcoming the free-rider problem in team production and improving social efficiency.

Our experimental setting for the GM fits into the class of contribution games in the Voluntary Contribution Mechanism (VCM) literature (Fehr and Gätcher, 2000; Baranski, 2016). In such games, each player can contribute tokens from some given endowment to a group fund which is then distributed among the players. While this game can fit into the category of games with positive externalities, since the group fund is always greater than the sum of the individual contributions, the flexibility in its distribution allows for the possibility that players can be excluded from a share of the fund. This restricts the usage of the GM in the context of pure public good games, as pure public goods are indivisible and non-excludable. Nevertheless, the GM remains applicable to a class of team production games or profit sharing models (Weitzman and Kruse, 1990; Heywood and Jirjahn, 2009), where the production function is additive and exhibits increasing returns. For this class of games, the GM is particularly useful if there is a principal or a team manager who cannot observe the contribution levels of the agents and whose payoff depends positively on the contributions of these agents.

In our view, such a simple mechanism is worthy of further study. It is cognitively less demanding than other mechanisms, and its simplicity should be an advantage in practical applications. In our introduction we noted its potential in assigning individual marks for student group work, and reported Galbraith's observations of its use for allocating bonus payments to some New York bankers in the 1920s. Baranski (2016) notes that similar profit allocation decisions arise in certain types of business partnership, such as accounting firms, law firms, management consultants, medical groups, and architects' consortiums. Of course any practical application can bring with it complications. For example, if the contributions take the form of real effort or real tasks by the agents, rather than "tokens", it becomes more difficult for the agents to map the effort/task levels they observe from their peers to the monetary value and to use this in their allocation. In the context of group class assignments the group members may know their relative contributions but they may not know the exact relationship between these individual contributions and the assignment's final grade.

We have introduced the GM in a simple but familiar context. Failure of the GM to produce efficiency gains in these experiments would not bode well for its success in more complex and realistic settings. Its success here therefore makes a case for further theoretical development and experimental testing. Separate pilot experiments involving a larger group size and introducing costs for players to acquire information about others' contributions indicate that the GM continues to give efficiency gains (Dong, 2017). Indeed, larger groups may make the GM even more effective. Because our players had identical endowments, we were unable to distinguish between egalitarian, proportional and super- and sub-proportional allocation behaviour when all players made full contributions. Allowing players to have different endowments would alleviate this identification problem. Finally, in our experiments player anonymity and rotation precluded the influence of any personal relationships on allocation decisions. In reality players would expect such relationships to exist and potentially both friendship and fairness to be factors influencing allocations. How this might affect allocation and contribution behaviour is a topic worthy of study.

Appendix A. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.geb.2019.02.016.

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