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Public Goods: Voluntary Contributions and Risk

Miguel A. Sánchez Villalba and Silvia Martínez-Gorricho*

Abstract

We analyze two incentive mechanisms as a way of financing public goods. Our mechanism can be interpreted as a variation of a parimutuel lottery in which the total rebate (prize) is made endogenous by setting it equal to a non-increasing function of total bets. The mechanism changes the nature of the standard VCM from a Prisoner's Dilemma to a Stag-Hunt game. We tested —and found support for— the theoretical predictions of the model by means of a computer-based experiment. The theoretical model and the supporting experimental evidence both suggest the mechanism is an efficient and equitable means to finance public goods through voluntary contributions. In policy terms, and beyond the efficiency and equity considerations, the mechanism would be easy to implement and run given its simplicity and self-sufficiency.

Keywords: Public Goods, Voluntary Contribution Mechanism, Subsidy Schemes, Laboratory Experiments.

JEL classification numbers: C72; C92; H41.

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1 Introduction

Pure public goods possess the feature that they are nondepletable (consumption by one individual does not affect the supply available for other individuals) and nonexcludable (exclusion of an individual from the benefits of a public good is impossible). The standard mechanism for the private provision of a public good, called the voluntary contribution mechanism (VCM) (first studied by Olson (1965)), relies on voluntary contributions. These characteristics of public goods imply that its private provision creates a situation in which positive externalities are present. The failure of each consumer to internalize the benefits conferred upon all other consumers of her public good provision is often referred as the free-rider problem and results in a systematic underprovision (low levels of public good contributions are a dominant strategy for each player) of the public good when it is socially desirable.[1]

The key to mitigating the free-rider problem in public good provision is to increase the private marginal benefit of contributions. A natural solution consists on designing mechanisms that are able to affect the relative price to agents of contributing to the public good.[2]

Linear subsidy/matching schemes to private spending that are financed through taxation (Roberts (1987,1992), Boadway, Pestieau and Wildasin (1989), Andreoni and Bergstrom (1995), Falkinger (1996) and Brunner and Falkinger (1999)) has been examined by the literature. These mechanisms require a degree of coercion that are not available to private organizations, such as charities, and therefore, cannot be implemented by these organizations.[3]

Several authors had advocated for the compensation mechanism which implements Lindahl-voluntary equilibria in a complete information environment using a two-stage game (Guttman (1978, 1985, 1987), Moore and Repullo (1998), Danzinger and Schnytzer (1991), Althammer and Buchholz (1993), Varian (1994a,b)). In

[1] Refer to the classical paper by Bergstrom, Blume and Varian (1985) for further discussion on the relevance of this model. Ledyard (1995) provides a good survey of the experimental evidence.

[2] A different solution is the introduction of a step-level provision point (a commonly known minimum threshold that contributions must meet or surpass for the public good to be provided to all members (Andreoni (1998)). With the provision point, the VCM is typically modeled by the game of Chicken, also known as the "Battle of the Sexes". There are no dominant strategies in this game and the zero contribution equilibrium is Pareto dominated by a positive-contribution equilibrium. However, coordination problems arise due to the multiplicity of positive-contribution equilibria. These equilibria form a set which cannot be Pareto ranked and create a conflict called the "cheap riding" problem (Isaac, Schmidtz and Walker (1988)) since it provides individual incentives to attempt to obtain an equilibrium outcome with unequal distribution of contributions.

[3] In these mechanisms, individuals are assumed not to have the right to opt out of the mechanism, that is, these mechanisms are not individually rational.

the first-stage, each agent (voluntarily) is able to influence the cost to the other agents of their contributions by simultaneously announcing constant subsidy/matching rates at which she is willing to subsidize the individual contributions of each of the other agents. In the second stage, players choose their individual purchases of the public good on the basis of the subsidy/matching rates announced in the previous stage. Any perfect equilibrium with a positive provision of the public good is a Lindahl equilibrium but it is possible that the economy might become trapped in a non-provision equilibrium which is pareto dominated by a Lindahl equilibrium with positive provision of the public good. In practice, these schemes are difficult to implement.

In all the previous papers, attention is restricted to subsidy/matching rates that are constant or flat. In this paper, we advocate for two incentive mechanisms that are based on nonlinear subsidy schemes. The first mechanism, called the Relative (Time) Subsidy Scheme (RTSS), owns its name to the key role played by a costless extra dimension (the timing of contributions) in generating price-discrimination among participants. Specifically, by heavily rewarding early contributions in relative terms, this mechanism introduces a negative externality among players through the play of a tournament which is shown to be successful in promoting the private provision of the public good. An exogenous risk originates from the variability in payoffs associated to the tournament. Behaviorally, this exogenous risk might have an impact on contribution decisions. From there, the importance of analyzing the behavioral response to the introduction of this incentive mechanism.

Lotteries are also individually rational mechanisms that obtain higher levels of public goods provision than standard voluntary contributions mechanisms. Lottery rules introduce additional *private* benefits from contributing (Morgan (2000)).[4]: when a consumer purchases raffle tickets, the public good provision is naturally increased as well as her *relative* chances of winning the private prize. In a fixed-prize lottery, the prize is fixed since it is a stipulated total rebate amount set aside from total contributions. The proceeds, net of the prize amount, are used to finance the public good. As Morgan points out fixed-prize lotteries can be seen as *nonlinear* subsidy schemes, being the subsidy rate of every individual inversely proportional to the total level of gross contributions made to the public good.[5] The fixed-prize lottery is an effective means of financing public goods relative to the voluntary contribution mechanism because this mechanism increases the marginal private benefit from contributing through a decrease in the opportunity cost. However, it cannot generate the socially optimal provision of the public good although it can come arbitrarily close to

[4] Experimental evidence on lotteries and auctions as methods to finance public goods is reported by Morgan and Sefton (2000), Orzen (2005), Schram and Onderstal (2007), Lange et al. (2007) and Lim and Matros (2009).

[5] Morgan employs the ratio form of the Contest Success Function (Tullock (1967, 1980)) with the "mass effect parameter" set equal to one. Refer to Hirshleifer(1989) for a comparison analysis of this success function relative to the difference form one.

its first-best level as the fixed-prize is made arbitrarily large[6] since bets increase in excess of the amount of the prize.

Morgan also analyzes pari-mutuel raffles, in which the prize amount is a stipulated constant fraction of the total wagers. A pari-mutuel lottery is outcome equivalent to a scheme with a flat or constant subsidy rate since the elasticity of the subsidy rate with respect to total gross contributions is null. This lottery is not effective at raising contribution levels because in addition to lowering the marginal cost of contributing (as the fixed-prize lottery does), it critically lowers the marginal gain from contributing by the same proportion (an extra dollar of contribution increases the public good provision in less than one dollar because it is partially used to finance the increase in the prize pool available to all the bettors).

Our second proposed mechanism is a variation of the pari-mutuel lottery, called the "hybrid " lottery, in which a *nonlinear decreasing fraction* of total gross contributions is rebated in the form of prizes. Clearly, the prize structure in the hybrid lottery has both fixed-price and a pari-mutuel components. The common feature shared by the fixed-prize lottery and the hybrid lottery is that both are non-linear subsidy schemes: the subsidy rate earned by each individual is nonlinearly decreasing in the total gross contribution levels. On the other hand, the prize amount is not fixed but endogenous. As in the pari-mutuel lottery, it is a fraction of total gross contributions and therefore, this mechanism is fully self-financing (budgetary illusion is excluded) irrespectively of whether subjects are in or out of equilibrium. This implies that the usual assumption of a money-back guarantee[7] is no needed. In contrast to the pari-mutuel lottery, this lottery does not dilute the negative externality component associated to the fixed-prize raffle since it creates an extra negative externality component: additional bets decrease the percentage of the total bets rebated in the form of prizes. In order to achieve efficiency, the prize amount must be decreasing in the gross contribution levels (over some range). This is a critical difference with the previous lottery types. It seems intuitive to conjecture that a decrease in the prize amount reduces the private marginal benefit from contributing. But this argument is incomplete. If the subsidy rate function is designed such that the elasticity of the subsidy rate function with respect to gross

[6] This result crucially relies on the assumption of non-binding wealth constraints for all consumers. If wealth-constraints are assumed to be binding, this result does not follow.

[7] In mechanisms such as the fixed-prize lottery and auctions it is generally assumed that if the total revenue is insufficient to cover the cost of the prize, then the charity calls off the raffle/auction and return each bettor's wager. Step-level provision points mechanisms also need a similar assumption. Isaac, Schmidtz and Walker (1988) show that the money-back guarantee must be complete and credible for it to be successful in promoting the provision of public goods in an environment characterized by the assurance problem: the fear of having one's contribution wasted if the provision point is not met.

contribution levels is sufficiently high[8] in absolute values, then the hybrid lottery is capable of increasing the private marginal benefit of contributing by furthermore than the fixed-prize lottery, eliciting greater private contributions to the public good. The negative externality exerted on the other gross contributors through further contributions to the public good is so powerful that relative to the fixed-prize lottery, the increase in the marginal private gain from contributing more than compensates the possible private increase in the opportunity cost of contributing. This key feature of the hybrid lottery makes of it a superior mechanism to the fixed-prize lottery and is crucial in attaining the first-best outcome. If properly designed, contributing the social optimal level could be made a weakly dominant strategy for each agent and zero payments in form of rebates (null prize) made in equilibrium by the organization.

Experimental data from voluntary contribution public goods environments report a frequent use of strictly dominated strategies. The persistence of cooperation in standard public good experiments is a well known phenomenon in the literature.[9] Subject's public contributions are much greater than predicted by standard economic theories of free-riding and these contributions decay over the course of multiple-round games.[10] Note that agents also often fail to contribute when it is in their own interest to do so (Saijo and Nakamura (1995)).[11] From there, the importance of testing our theory in the laboratory.

Our proposed mechanisms change the public good game from a Prisoner's Dilemma to a Stag Hunt game which raises an equilibrium selection problem and the possibility of coordination failure on the Pareto efficient equilibrium. We evaluate our theoretical conjectures via a series of experimental treatments that examines the contribution decisions of agents across a number of settings. We ran 6 treatments (all of them using neutral terminology):

- Treatment VCM: one standard VCM treatment to be used as benchmark for comparison;
- Treatment $E(xogenous)$: individual rebates are a function of the individual absolute time of contribu-

[8] The elasticity of the subsidy rate function with respect to gross contribution levels in absolute values is equal to one in the fixed-prize lottery case and zero in the pari-mutuel lottery case.

[9] Several explanations have been offered in the literature for why there is so much cooperation: kindness (altruistic preferences, warm-glow preferences) and "confusion" or decision error. Both explanations bias contributions upwards. See Andreoni (1995), Palfrey and Prisbrey (1997) and Anderson et al. (1998)

[10] Subjects generally begin by contributing about half of their endowments to the public good. As the game is iterated, the contributions "decay" toward the dominant strategy level and stand at about 15-25% of the endowment by the tenth iteration (Isaac and Walker (1988). The declines in contributions might be consistent with learning and endgame effects.

[11] Saijo and Nakamura do not justify their results by arguing confusion but by arguing the presence of many spiteful subjects, those who free ride in order to maximize ranking.

tion. This treatment is run to test for framing effects;

- Relative Time Subsidy Schemes: Two other treatments in which rebates are a function of the relative time of contribution, each one of them presenting a different combination of exogenous and endogenous risk levels, namely
  - Treatment $B(ase)$: both types of risk are strictly positive. Contributing is the unique best response if and only if at least two other players (within a group of a total of four subjects) contribute. This treatment is used as the basis for comparison with all other treatments;
  - Treatment $D(ominant)$: the exogenous risk is as in the B treatment and the endogenous risk is eliminated since contributing is made a (weakly) dominant strategy.
- Hybrid Lotteries: Two treatments in which every contributor receives the same rebate (eliminating the exogenous risk) and rebates are a function of total gross contribution levels. Each treatment is associated to a different degree of endogenous risk:
  - Treatment $A(verage)$: the endogenous risk is positive and it has the same value as in the B treatment.
  - Treatment $C(ertain)$: the endogenous risk is eliminated since contributing is made a weakly dominant strategy.

The predicted Nash equilibrium individual contribution level is null in treatments VCM and E while there exist multiple (two) Nash equilibria (the full contribution equilibrium and the zero contribution equilibrium) in the rest of the treatments. Our hypotheses are such that we could order treatments in terms of their performance (number of contributors and net contributions per capita), behaviorally having both exogenous and endogenous risk a negative impact on their performance. The following ordering of the treatments $C \sim A \succ D \sim B \succ E \sim VCM$ was obtained. Our main findings are that:

- Both mechanisms are effective means of financing public good provision (both mechanisms perform significantly better than the VCM).
- Controlling for endogenous risk, offering rebates with no variability in payoffs (no exogenous risk) increases significantly performance. As a result, the hybrid lottery outclasses the Relative Time Subsidy Scheme mechanism in eliciting contributions.

- Controlling for exogenous risk, the elimination of endogenous risk does not significantly increase performance.

Surprisingly, empirical evidence seems to reject the idea that endogenous risk plays a significant role in the individual's decision. We do not have a definitive explanation for this anomaly.

To sum up, the originality of our paper is twofold. We prove theoretically and evaluate experimentally the distinct properties shared by the relative time mechanism and the hybrid lottery. These incentive mechanisms are effective, easy to understand, simple to implement, cheap and self-financed. The hybrid lottery is further equitable and efficient. The results suggest that both incentive mechanisms could be successfully applied to real life situations.

The paper is organized as follows. A simple linear version of the public good game with homogeneous agents and complete information is formalized in section 2. Section 3 compares private provision via the different proposed mechanisms, including the relative time subsidy scheme and the hybrid lottery. Experimental designs and tests of many implications of the theory are introduced in section 4. Section 5 presents the results of our experiments. Section 6 concludes with a discussion of directions for future research.

2 The Model

Consider a very simple simultaneous linear public game with N homogeneous and risk neutral expected utility maximizer agents. Each consumer i consumes a non-negative amount x_i of the private good and donates a non-negative amount g_i to the supply of the public good. The total supply of the public good, $G = \sum_{i=1}^{N} g_i$, is the sum of the contributions made by all individuals. Each player's preferences are represented by the payoff function: $u_i(x_i, G) = x_i + \gamma G$, where $\gamma \in \left(\frac{1}{N}, 1\right)$[12] is the marginal per capita return (MPCR). Each individual i is endowed with wealth w[13] which she allocates between her consumption of the private good and

[12] This range is the most interesting parameter constellation because as it is shown below, it implies a tension between social efficiency and individual incentives under voluntary contributions.

[13] This simple model conveys much of the intuition of the general results presented in section 7 under the assumption of heterogeneity in wealth and/or preferences among agents. Homogeneity can also be useful to shed light on some interesting cases. In particular, it could be applicable to political-economy models in which each citizen has only one vote. The allocation of wealth between private consumption and contribution can be linked to the selection of a politician/candidate that would implement the corresponding tax rate, assuming that the technology that transforms votes into policies is the electoral rule/legislative procedure.

her private contribution to the public good. Let G_{-i} denote the sum of all contributions done by consumers other than i.

Definition 2.1. A Nash equilibrium in this model is a contribution profile g^* such that for every player i, (x_i^*, g_i^*) solves

$$\max_{x_i, g_i} \; u_i(x_i, g_i + G_{-i}^*) = x_i + \gamma(g_i + G_{-i}^*)$$

$$st. \; x_i + g_i \leq w$$

$$x_i \geq 0, \;\; g_i \geq 0$$

Although there does not exist an explicit cost of investing in the public good, there exists an implicit opportunity cost in terms of foregone private consumption. Given that $\gamma < 1$, each individual's opportunity cost of contributing to the public good exceeds her marginal return of investing in the public good. Clearly, not contributing to the public good strictly dominates any player's other action. Therefore, the unique equilibrium contributions induced by the Voluntary Contribution Mechanism (VCM) are zero, and as a result, the public good is not provided in equilibrium.

On the contrary, the social optimum[14] contribution profile $\hat{g}$ solves:

$$\max_{\{g_i\}} \sum_{i=1}^{N} u_i(w - g_i, G) = Nw - G + N\gamma G$$

$$st. \; 0 \leq \sum_{i=1}^{N} g_i \leq Nw$$

Given that $N\gamma > 1$, social welfare is maximized by contributing all aggregate wealth to the public good, $\hat{G} = Nw$. Hence, efficiency is achieved whenever each agent contributes her entire endowment to the public good provision: $\hat{g}_i = w \; \forall i$.

Our environment is characterized by extreme free riding when in fact, the public good is socially desirable. The VCM results in a systematic underprovision of the public good relative to the first-best allocation. Our goal in this paper is designing a mechanism that induces larger (even first-best) contributions to the supply of the public good.

[14] We follow most of the literature by assuming a utilitarian social welfare function.

3 Subsidy Schemes

In this section, different budget balancing subsidy schemes are analyzed. An extra costless dimension, called "the timing of contributions", is introduced into the consumer's problem in some of the schemes. Now, each agent simultaneously decides not only whether to contribute or not and by how much, but also *when* to make her pledge without observing the decisions made by the other agents. Note that the game continues to be a static (simultaneous) game. The timing of contributions is a simple artifact[15] that allows us to generate price discrimination through a time dependent subsidy scheme. Specifically, the opportunity cost of contributing to the supply of the public good is lowered for earlier contributions.

Given the added complexity introduced by the time variable and the subsidies, we focus on a simpler version of the game characterized by binary gross contributions only.[16] Each agent must decide privately whether to gross contribute her total endowment to the public good or refrain from contributing: $k_i = \{0, w\}$.[17] This is as if the individuals were endowed with an indivisible amount of the private good[18].

We can define the following gross contribution indicator variable:

$$\kappa_i = \begin{cases} 1 & \text{if } k_i = w \\ 0 & \text{if } k_i = 0 \end{cases}$$

Let $k \in \{0,1\}^N$ be a profile of gross contributions. Let time be a continuous variable that starts at 0 and runs indefinitely. Let t_i denote player i's contribution time: the time at which player i chooses to gross contribute to the public good if (he decides to do) so. Let $t \in R_+^N$ be a profile of contribution times.

Each player's action space is $\{w, 0\} \times R_+$. Player i's preferences can be rewritten as:

[15] Several other variables, instead of the timing of contributions, could have been selected as long as they satisfy two main characteristics: (i) all agents are homogeneous in its regard and (ii) it is costless, hence preserving the structure of the original game.

[16] As Bergstrom et all (1986) acknowledge "adjustments on the "extensive" margin -the decision of whether or not become a contributor- are at least as important as adjustments on the "intensive" margin -the decision of how much to contribute. In general, only a small subset of consumers will actually contribute to the public good. Thus, the usual practice of assuming interior solutions is quite misleading" (Page 27).

[17] Given the linear structure of the payoff function, at least one of the corner solutions must be an optimal allocation. Thus, the analysis is simplified by restricting the gross contribution strategy space to corner solutions, allowing subjects to focus on the "extensive" margin and timing decision.

[18] This assumption is made for the purpose of illustration. Our central results obtained in this simple version of the model can be easily extended to the case of a divisible endowment

$$u_i(k,t) = s_i(k,t) + (1-\kappa_i)w + \gamma\left(\sum_{j=1}^{N} k_j - \sum_{j=1}^{N} s_j(k,t)\right)$$

where $s_i(k,t)$ denotes the total subsidy (instantaneous cash rebate) obtained by player i in the game. The public good provision is given by the sum of all gross contributions in excess of the total subsidy payments. Thus, each player's net contribution to the public good is in turn equal to the player's gross contribution minus the rebate: $g_i(k,t) = k_i - s_i(k,t)$.[19] Individual subsidies are assumed to be bounded above by their gross contributions: $s_i(k,t) \leq k_i$ for all (k,t) profiles. Therefore, the mechanism designer never pays a net transfer to any agent, $g_i(k,t) \geq 0$ $\forall i$, satisfying the non-negativity constraint of the original game (in and out of equilibrium). Note that several proposed mechanisms such as lotteries and auctions violate this property (at least, out-of-equilibrium).[20] This feature also guarantees that the mechanism is self-financing. For individuals to have the right to opt out of the mechanism, $s_i(k,t) \geq 0$ if $k_i = 0$. For total net contributions to the public good to be maximized, $s_i(k,t) = 0$ if $k_i = 0$. Therefore, through out the paper, only contributors are assumed to be eligible for rebates.

The standard VCM corresponds to the no subsidy case, that is, $s_i(k,t) = 0$ for all i and (k,t) profiles. This implies that each individual's gross and net contributions to the public good coincide: $g_i(k,t) = k_i$ $\forall i$.

3.1 The Absolute Time Subsidy Scheme

Under the Absolute Time Subsidy Scheme (ATSS), the subsidy function faced by player i only depends on her contribution decision and the contribution time chosen by player i: $s_i(k,t) = s(k_i, t_i)$ $\forall i$. Since $s_i(k,t)$ is independent of the decisions taken by the other agents, no additional externalities to the ones introduced by the VCM are present under this scheme.

This scenario resembles a "for a limited time only" market sale promotion.[21]

[19] The presence of subsidies relaxes the restriction of a binary contribution. Those individuals who benefit from a subsidy can enjoy a positive private consumption level despite gross contributing the entire endowment.

[20] Given this violation, it is not surprising that that public good provision is higher when financed by these proceeds than when financed by voluntary contributions.

[21] This kind of promotion is very popular and spread around the world. One example refers to waived fees applied to early registrations for a scientific conference. Another example of this type of promotion was in place some time ago in the province of Tucumán (Argentina), where the taxpayers were waived one of the bimonthly instalments of the property tax if all of them were paid at the beginning of the fiscal year.

Formally, $s_i(k,t) = \kappa_i \cdot \delta(t_i)$, where $\delta(\cdot)$ is a monotonically non-increasing function in player i's contribution time and such that $\delta(0) \leq w$. Player i's preferences are represented by the payoff function:

$$u_i(k,t) = \kappa_i \cdot \delta(t_i) + (1-\kappa_i)w + \gamma \sum_{j=1}^{N} \kappa_j (w - \delta(t_j))$$

Proposition 3.1. *Under the Absolute Time Subsidy Scheme, the net public good provision is null in any Nash equilibrium.*

Proof. A Nash equilibrium in this model is a gross contribution and time profile (k^*, t^*) such that for every player i, (k_i^*, t_i^*) solves

$$\max_{\{k_i,t_i\}} u_i(k,t) = w - (1-\gamma)\kappa_i(w - \delta(t_i)) + \gamma \sum_{j \neq i} \kappa_j^* (w - \delta(t_j^*))$$

If $\delta(0) < w$, then $w - \delta(t_i) > 0$ for all t_i. Given that $\gamma < 1$, "refrain from contributing" $((0, t_i)\ \forall t_i)$ is the *unique* best response of each player to any other players' strategies. If $\delta(0) = w$, let $\tilde{t}$ be the largest time instant for which the subsidy obtained by any player is equal to the wealth endowment, that is, $\delta(t_i) = w$ if and only if $t_i \leq \tilde{t}$. The strategy "refrain from contributing" $((0, t_i)\ \forall t_i)$ continues being a best response to any other players' strategies. Furthermore, the strategy "contribute at a time instant not larger than $\tilde{t}$ " $((w, t_i))$ for $t_i \leq \tilde{t})$ is also a player i's best response to the other players' strategies. No further best responses (in pure strategies) exist. As a result, in any Nash equilibrium outcome, the sum of all gross contributions exactly equals the total subsidy payments so that the public good is not provided in equilibrium: $G^* = \sum_{j=1}^{N} g_j^*(k,t) = \sum_{j=1}^{N}(k_j^* - s_j^*(k,t)) = 0$. □

Define $K_{-i} = \sum_{j \neq i} k_j$. Note that $u_i((w, K_{-i}), t) - u_i((0, K_{-i}), t) = (1-\gamma)(-w + \delta(t_i)) < 0$. Intuitively, the subsidy scheme decreases the opportunity cost of contributing (for any given gross contribution, the private consumption level is now greater) and the marginal return of investing in the public good (the amount of the public good supplied is now lower) by the same proportion. Therefore, this mechanism is completely ineffective at mitigating the extreme free-riding problem since it continues being a pervasive outcome of the public good game. The ATSS is strategically equivalent to a pari-mutuel lottery or a flat subsidy scheme. [22]

Theoretically, this mechanism has no impact (relative to the standard VCM) on the private provision of the public good. The important next step is to evaluate how it performs experimentally. Our E(xogenous

[22] The total amount of the subsidy rebated to the agents (given the contributing time decision made by potential contributor) is linear in the total gross contribution to the public good.

time) treatment resembles this set up. The chosen subsidy function satisfies $\delta(0) < w$ so that in equilibrium $k_i^* = 0 \ \forall i$. The theoretical prediction suggests the following hypothesis:

Hypothesis 3.1. *The Absolute Time Subsidy Scheme (ATSS) is neither a superior nor inferior fundraising method than the standard VCM in terms of public good provision. The total number of contributors and the aggregate level of net contributions to the public good are not significantly different in the former than in the latter.*

3.2 The Relative Time Subsidy Scheme

If properly designed, a time-dependent price discrimination subsidy scheme could be successful in promoting the provision of the public good by generating a negative externality via competition among contributors to get the subsidies. This artificially generated negative externality helps reducing the gap between the private and socially marginal benefit from contributing.

This mechanism can be modeled as a (within-group) tournament game[23] being the subsidy payments the multiple prizes offered. Only contributors are eligible for a subsidy. Each contributor is paid a (lump-sum) subsidy based on how her contribution time ranks in comparison to the other contributors' contribution times. Players are ranked in decreasing order of their time of contribution. The agent with the shortest contribution time among contributors gets the highest subsidy; the contributor with the second shortest contribution time gets the second highest subsidy and so on. The tie-breaking rule is such that players contributing at same time share the subsidies equally in expected terms. The subsidy payments are such that the cumulative average subsidy weakly decreases as we go down the ranking. Formally, let $\delta \in R_+^N$ be a row vector of subsidies such that $\delta_j \leq w \ \forall j = 1, ..., N$ and that $\bar{\delta_j} \geq \bar{\delta}_{j+1} \ \forall j = 1, ..., N$ with strict inequality for at least some j, where $\bar{\delta_j} \equiv \frac{1}{j} \sum_{i=1}^{j} \delta_i$.

This scenario is a variation of the popular "while stocks last" market sale promotion in which early contributors get a positive discounts (greater subsidies than late contributors). However, the rebate (subsidy rate) is not necessarily uniform or flat for the early contributors in our environment. It is clear that this scheme introduces additional externalities to the ones generated by the VCM.

Three main features of this mechanism are notable:

[23] It can also be considered a "game of timing" in the sense that each player's payoff depends sensitively on whether her contribution time (if she chooses to be a contributor) is greater or less than the other contributors' contribution times. However, the particular times chosen at which to act do not have the ability to influence the payoffs earned as long as the time ranking is preserved (the prize amounts, in this case the rebates, are not dependent on the time profile).

i. Its zero-sum nature in the timing of contributions. Gross contributing the endowment but not immediately does not increase aggregate benefits (relative to doing so immediately) but it could merely cost the contributor and benefit other group members. Thus, contributing immediately is a weakly dominant strategy for any *potential contributor*. Indeed, if the subsidy payments are appropriately chosen, all contributions will be done immediately in equilibrium so that there is no delay in equilibrium in spite of agents being extremely patients (players do not discount future payoffs).

ii. Contrary to fixed prize lotteries, contests and auctions[24], positive rebates are only earned by (early) contributors so that the total amount *awarded* in terms of rebates (prizes) is made endogenous. Given that an endogenous weakly *decreasing percentage* of total gross contributions is rebated in the form of "prizes", the total amount of rebates *offered* is designed as a weakly increasing and weakly concave *function* of total gross contributions.

iii. The tournament game, as the VCM, is not a zero-sum game in the decision of whether or not become a gross contributor. Contrary to the VCM, cooperation in terms of gross contributions to the public good can be effectively incorporated into the incentive structure of this mechanism. If the subsidy function is properly designed, the public good game can be modeled by the Stag Hunt game instead of the Prisoner's Dilemma, and therefore, this mechanism can outperform the VCM.

We proceed proving these features and shedding light on the intuition of its effectiveness.

We start characterizing the potential Nash equilibria of the game with positive net private contributions to the public good. However, note that a continuum of equilibria characterized by a null (net) private provision of the public good exists[25].

Proposition 3.2. *Under the Relative Time Subsidy Scheme (RTSS), if the underlying subsidy scheme is not flat and shows a weakly decreasing cumulative average, then gross contributing the endowment immediately is a weakly dominant strategy for any potential contributor. If the number of contributors is sufficiently large, all contributors contribute immediately (there is no delay) in equilibrium.*

[24] These mechanism generally assume that the prize is awarded even when all individuals bid/bet zero. In this situation, it is assumed that equal probabilities of winning the prize are assigned to all individuals in the group.

[25] It is clear that if all other agents refrain from contributing to the public good and $\delta_1 < w$, the unique best *first component* response of any player to the other players' strategies is refraining from contributing and as a result, the public good is not privately provided in equilibrium. If all other agents refrain from contributing to the public good and $\delta_1 = w$, then any possible strategy is a best response to the other players' strategies. A continuum of equilibria is obtained due to the fact that any time of contribution is a best (*second component*) response in these cases.

Proof. Note that $\bar{\delta}_{j+1} \leq \bar{\delta_j}\ \forall j = 1, ..., N$ implies $\delta_{j+1} \leq \bar{\delta_j}\ \forall j$ and given $\bar{\delta_1} = \delta_1$, $\delta_{j+1} \leq \delta_1\ \forall j$. A player i who contributes at $t_i > 0$ never stands to gain relative to the situation in which she contributes immediately but she stands not to win the highest possible subsidy in some cases (when the other players' shortest contribution time is between 0 and her contribution time, that is, $t_i \geq min(t_{-i}) \geq 0$ with at least some strict inequality). Hence, a potential contributor's contribution time equal to zero weakly dominates all her other contribution times. Suppose that $\underline{n(\delta)} < n \leq N$ players choose to contribute to the public good at different time instants where $\underline{n(\delta)}$ is a natural number such that $\delta_j = w\ \forall j \leq \underline{n(\delta)}$ and $\delta_{\underline{n(\delta)}+1} < w$. Lets partition the set of contributors according to their contribution times. Let $\bar{\delta}_s$ denote the expected subsidy earned by each of the members of the subset characterized by the shortest contribution time. If the partition (collection of subsets of the contributors set) contains at least two subsets, there must be at least one subset of players who are not members of the subset characterized by the shortest contribution time and who earn an expected subsidy strictly lower than $\bar{\delta}_{s+1}$. Hence, any of these players can obtain a strictly higher expected payoff if she deviates by choosing a contribution time such that no player contributes to the public good earlier than her. As a result, all contributors must contribute at the same time instant. Suppose they contribute at a time moment different from zero. Then, any player can obtain a strictly higher expected payoff if she deviates and chooses a contribution time of zero, thus becoming the first contributor and earning δ_1. $\square$

Fix a rebate vector δ and let $n^*(\delta)$ be the total number of contributors in equilibrium: $n^*(\delta) \equiv \sum_{j=1}^{N} \kappa_j^*$. The expected subsidy obtained by any contributor in equilibrium is $\bar{\delta}_{n^*(\delta)}$[26] where $\bar{\delta}_{n^*(\delta)} \equiv \frac{1}{n^*(\delta)} \sum_{j=1}^{n^*(\delta)} \delta_j$. The equilibrium expected payoff earned by any gross contributor player i is: $u_i^w(K_{-i}^*(\delta)) = \bar{\delta}_{n^*(\delta)} + \gamma n^*(\delta)(w - \bar{\delta}_{n^*(\delta)})$ while the equilibrium expected payoff earned by any non gross contributor player l is: $u_l^0(K_{-i}^*(\delta)) = w + \gamma n^*(\delta)(w - \bar{\delta}_{n^*(\delta)})$.

The necessary condition for any given contributor not willing to deviate and refrain from contributing is:

$$\bar{\delta}_{n^*(\delta)} + \gamma n^*(\delta)(w - \bar{\delta}_{n^*(\delta)}) \geq w + \gamma((n^*(\delta) - 1)(w - \bar{\delta}_{n^*(\delta)-1})$$

This condition can be rewritten as:

$$\gamma(w - \delta_{n^*(\delta)}) \geq w - \bar{\delta}_{n^*(\delta)} \ \Leftrightarrow\ \bar{\delta}_{n^*(\delta)} \geq (1-\gamma)w + \gamma\delta_{n^*(\delta)} \tag{1}$$

This condition states that the opportunity cost of gross contributing w to the public good for a contributor, $(w - \bar{\delta}_{n^*(\delta)})$, cannot exceed the marginal gains obtained from her contribution: $\gamma(w - \delta_{n^*(\delta)})$. Under this

[26] This follows from the above proposition if $n^*(\delta) > \underline{n(\delta)}$. Otherwise, all contributors earn in equilibrium $w = \bar{\delta}_{n^*(\delta)}$.

mechanism, the (marginal) contributor is net contributing $(w - \delta_{n^*(\delta)})$ to the public good provision while she ends up paying only $(w - \bar{\delta}_{n^*(\delta)})$, a lower amount. This condition specifies a lower bound for the expected rebate obtained by any gross contributor in any equilibrium (characterized by positive contributions) of the game. This lower bound corresponds to a particular convex combination of the wealth endowment and lowest rebate earned by a contributor being the convex combination parameter the MPCR. The decreasing nature in rank of the expected rebates is crucial for the satisfaction of this condition. To see this, we can rearrange condition (1):

$$\delta_{n^*(\delta)}\left(\gamma - \frac{1}{n^*(\delta)}\right) \leq \left(\frac{n^*(\delta)-1}{n^*(\delta)}\right)\bar{\delta}_{n^*(\delta)-1} - (1-\gamma)w$$

This condition can be seen to specify an upperbound for the marginal subsidy earned in equilibrium if the number of contributors is sufficiently large $(n^*(\delta) > \gamma^{-1})$. If this is the case, this condition implies:

$$\delta_{n^*(\delta)} \leq \bar{\delta}_{n^*(\delta)-1} - \left(\frac{n^*(\delta)(1-\gamma)}{n^*(\delta)\gamma - 1}\right)(w - \bar{\delta}_{n^*(\delta)-1}) \;\Rightarrow\; \bar{\delta}_{n^*(\delta)} \leq \bar{\delta}_{n^*(\delta)-1}$$

If there were agents who did not contribute in equilibrium $(n^*(\delta) < N)$, the additional necessary condition that must be satisfied for these no contributors not willing to deviate and gross contribute their wealth endowment is:

$$\gamma(w - \delta_{n^*(\delta)+1}) \leq w - \bar{\delta}_{n^*(\delta)+1} \;\Leftrightarrow\; \bar{\delta}_{n^*(\delta)+1} \leq (1-\gamma)w + \gamma\delta_{n^*(\delta)+1} \tag{2}$$

This condition specifies an upper bound for the expected rebate that would be obtained by any non-contributor who deviated by contributing her wealth to the public good.

Under the Relative Time Subsidy Scheme (RTSS), and for a given rebate vector $\delta \in R^N$, multiple (pure strategy) Nash equilibrium outcomes, characterized by multiple positive net public good provision levels, might exist in the linear public good game. We can prove this statement by showing a simple numerical example. Assume that N, and $\delta = (1, 1, ..., 1, 0) \cdot w$. Under these assumptions, $n^*(\delta) = \{0, 1, ..., N-2, N\}$ and the net public good provision is $G^*(\delta) = \{0, 0, ..., 0, 1\} \cdot w$ respectively. Another numerical example is given by $N = 4$, $\gamma = \frac{3}{5}$ and $\delta = \left(1, \frac{17}{45}, \frac{2}{9}, 0\right) w$. Under these assumptions, the cumulative average subsidy function is strictly decreasing $\bar{\delta} = \left(1, \frac{31}{45}, \frac{8}{15}, \frac{2}{5}\right) w$. It follows that $n^*(\delta) = \{0, 2, 3, 4\}$ and $G^*(\delta) = \{0, 2w - \frac{62}{45}, 3w - \frac{8}{5}, 4w - \frac{8}{5}\} \cdot w$. Likewise, there might be no Nash equilibrium characterized by a positive net public good provision level. For example, this is the case under the assumptions $N = 4$, $\gamma = \frac{3}{5}$ and $\delta = \left(\frac{3}{5}, \frac{2}{5}, \frac{1}{5}, 0\right) w$, which imply $\bar{\delta} = \left(\frac{3}{5}, \frac{1}{2}, \frac{2}{5}, \frac{3}{10}\right) w$, $n^*(\delta) = 0$ and $G^*(\delta) = 0$. Note that the zero contribution profile is always an equilibrium due to the restriction that individual subsidies are bounded above by their gross contributions levels. As a result, gross contributing the endowment can be made at most a weakly dominant strategy.[27] The rebate vector could be designed in such a way that the full contribution profile is a Nash equilibrium and furthermore, that no partial contribution equilibrium exists, that is, $n^*(\delta) = \{0, N\}$. If this is the case, the Nash equilbrium outcomes in the linear public good game are reduced to two: one in which all players are gross contributors and there is no delay in equilibrium and one in which no one contributes to the public good. The first equilibrium outcome corresponds to a strict Nash equilibrium that Pareto dominates any Nash equilibrium characterized by a zero public good provision, becoming a focal equilibrium to be played in the game. With this design any possible coordination issues that agents might face when playing the game are reduced. The design of the subsidy scheme can be done in such a way that it satisfies further refinements such as Risk Dominance.

Assume any rebate vector $\delta \in R_+^N$. The equilibrium social welfare, defined as the sum of individual utilities, is given by:

$$W^*(\delta) = Nw + (N\gamma - 1)n^*(\delta)(w - \bar{\delta}_{n^*(\delta)})$$

The private provision of public good is given by the equilibrium net contributions to the public good $G^*(\delta) = n^*(\delta)(w - \bar{\delta}_{n^*(\delta)})$ while the percentage of total net contributions to the public good over aggregate wealth is given by $\frac{G^*(\delta)}{Nw} = \frac{n^*(\delta)}{Nw}(w - \bar{\delta}_{n^*(\delta)})$.

It is clear that the greater is the private provision of the public good, the better off is the society in equilibrium. The equilibrium private provision of the public good is dependent on the rebate vector through two variables: the equilibrium number of contributors and the expected rebate obtained in equilibrium. The larger is the number of contributors and the lower is the expected rebate, the greater is the private provision of the public good and the social well being. In order to maximize welfare, the rebate vector chosen should satisfy that: (i) all players contribute in equilibrium ($N \in n^*(\delta)$); and (ii) the expected rebate earned by gross contributors in equilibrium is the lowest value that permits the satisfaction of condition (1).

Importantly, gross contributing the entire wealth endowment immediately can be made to be a *weakly dominant* strategy for every player. This fact greatly simplifies the player's problem since gross contributing the entire endowment immediately is now an optimal action regardless of her opponents' actions. If every player follows this strategy, the resulting Nash equilibrium is symmetric. Although the mechanism has multiple Nash equilibria, the equilibrium in which every player's gross contribution is equal to her wealth

[27] Note that a necessary condition for this strategy to be weakly dominant is $\delta_1 = w$. If, as in Morgan (2000), it is assumed that the organization or charity has access to an arbitrarily small amount of deficit financing of ε, then by setting $\delta_1 = w + \varepsilon$, gross contributing the entire endowment might be made a *strictly dominant* strategy by eliminating the existence of the zero contribution equilibrium.

endowment and it is done immediately, is distinguished by the fact that every player's strategy weakly dominates her other strategies.

Proposition 3.3. *Under the Relative Time Subsidy Scheme (RTSS), there always exists a subsidy scheme such that gross contributing the entire wealth endowment immediately is a weakly dominant strategy for all players.*

Proof. Consider any subsidy scheme δ such that $\delta_n = w \ \forall n \leq \gamma^{-1}$ and $\delta_n \leq \bar{\delta}_{n-1} - \left(\frac{n(1-\gamma)}{n\gamma-1}\right)(w - \bar{\delta}_{n-1}) \ \forall n > \gamma^{-1}$ satisfies $\bar{\delta}_n \leq \bar{\delta}_{n-1}$ with at least some strict inequality. The subsidy scheme is not flat and shows a weakly decreasing cumulative average. By applying proposition (3.2), we get the result: $u_i^w(K_{-i}) \geq u_i^0(K_{-i}) \ \forall K_{-i}$. □

Theoretically, we should expect this mechanism to have a significant impact (relative to the standard VCM) on the private provision of the public good. The important next step is to evaluate how it performs experimentally. The theoretical analysis suggests testing the following hypothesis:

Hypothesis 3.2. *The Relative Time Subsidy Scheme (RTSS) is a superior fundraising method to the standard VCM in terms of public good provision. The total number of contributors and the aggregate level of net contributions to the public good are significantly higher under the RTSS than under the VCM.*

Our B(ase) and D(ominant) treatments resemble this set up. The main difference across these treatments is that gross contributing the entire endowment is a weakly dominant strategy under the D(ominant) treatment whereas it is not under the B(ase) treatment.

3.2.1 Efficiency and First-Best Outcome

In this subsection, the mechanism is compared to the ATSS and the intuition of our results on the efficiency properties of the RTSS is explained. We end the subsection showing that this mechanism fails in achieving the first-best outcome. Despite this failure, its successfulness in inducing contributions from players is such that it outperforms any fixed-prize raffle in all welfare criteria cited above.

RTSS vs. ATSS, pari-mutuel lotteries and other flat subsidy schemes. The main difference among these mechanisms is the previously mentioned feature (ii)[28]. As cited above, constant or flat subsidy schemes

[28] Although the ATTS is not a zero-sum game in the timing of contributions, it also satisfies that contributing immediately is a weakly dominant strategy for any potential (non-altruistic) contributor and hence, both are outcome equivalent in the timing decision by any potential (non-altruistic) contributor.

violate condition (1). The subsidy scheme applied under the RTSS is such that a *(weakly) decreasing percentage* of total gross contributions is rebated in the form of prizes, allowing the satisfaction of this condition.

This explanation suggests testing the following hypothesis:

Hypothesis 3.3. *The RTSS is a welfare improving fundraising mechanism relative to the ATSS. The total number of contributors and the aggregate level of net contributions to the public good are significantly higher under the RTSS than under the ATSS.*

In order to reach the first-best level of public good provision it is needed that every player *net* contributes her entire wealth endowment to the public good in equilibrium. In turn, this can be accomplished only if: (i) every player gross contributes her wealth endowment in equilibrium ($k_i^* = w \ \forall i$) and (ii) the expected rebate/subsidy earned by every player is zero in equilibrium. Under the assumption $\delta \in R_+^N$, a necessary condition for $\bar{\delta_N} = 0$ is $\delta_j = 0 \ \forall j = 1, ..., N$, but then condition (1) would be violated. Hence, this mechanism cannot attain the first best level of public good provision. The maximum level of welfare and public good provision attainable are $W^* = [1 + \gamma(N\gamma - 1)]Nw$ and $G^* = \gamma Nw$. They can be obtained by setting $\delta_N = 0$ and $\bar{\delta_N} = (1 - \gamma)w$. These social welfare and public goods provision levels are increasing in γ and approach first-best levels as γ tends to one. It can easily be shown that these social levels are strictly larger than the ones generated by any fixed-prize lottery (refer to footnote (38)) and at least as large as the ones generated by a first-price all-pay auction.[29] Refer to Sánchez Villalba et all. (2011c) for an experimental evaluation of the relative performances of the following incentive mechanisms in public good games: a fixed-prize lottery, a hybrid lottery and all-pay auctions.

A simple variation of this mechanism, which is capable of accomplishing the first best level of public good provision, is analyzed in the next section.

[29] There exist multiple (both symmetric and asymmetric) Nash equilibria in pure strategies in the First-Price All-Pay Auction. Assume that if the revenue generated by the auction is lower than the prize or the value of the object on sale (denoted by R), then the auction is called off. The full wealth endowment contribution profile is a Nash equilibrium if and only if $R \geq (1-\gamma)Nw$ so that $G \leq \gamma Nw$ and $W \leq [1+\gamma(N\gamma-1)]Nw$. The levels of welfare and public good provision attainable with this mechanism are no greater than the ones induced by the RTSS.

3.2.2 Usefulness of the Time Dimmension

Substantial discrepancies between actual and predicted behavior are often observed in standard public-good experiments. First, subjects tend to be more cooperative than predicted. Andreoni (1995) states that "kindness (notions of benevolence or social customs such as pure altruism, warm-glow, reciprocity, group ethics and fairness) and confusion (some subjects misunderstand the instructions or the incentives in the experiment and are incapable of deducing the dominant strategy) are equally important in generating cooperative moves in public-goods experiment". His experiment attempts to separate both motives and reveals that "on average about 75 percent of the subjects are cooperative, and about half of these are confused about incentives, while about half understand free-riding but choose to cooperate out of some form of kindness" (page 900). Second, these contributions decay over the course of multiple-round games. Different theories have been postulated to explain this result. One such theory is "learning" the free-riding incentives which essentially accounts for reductions in confusion: high initial contributions decay mainly because subjects gradually come to understand the game's incentives. Andreoni finds that "most of the learning in his experiment was accomplished in the first five rounds... The movement toward the equilibrium in the last half of the experiment appeared to be due to frustrated attempts at kindness". For some individuals, kindness may depend on reciprocity: some subjects make contributions in order to elicit contributors from reciprocators in subsequent rounds. Hence, as confusion is gradually reduced, these confused individuals start learning the dominant strategy and free ride. The lack of sufficient reciprocity by these individuals reduce the propensity of the socially motivated subjects to contribute.

Following Andreoni (1995), it could be argued that the zero-sum structure of the tournament game leaves no incentives for any cooperation or reciprocal altruism in the timing of contributions. Gross contributing the endowment but not immediately does not increase aggregate benefits[30] (relative to doing so immediately) but merely cost the contributor and benefit other group members. This fact should be trivial for the subjects (there is no need to perform any computation to realize it). Therefore, we attribute any not immediate cooperation in these treatments to confusion contributions (and not to social motives[31]).

[30] Subjects might be altruistic, that is, they might care about the payoffs of the other subjects. Formally, a pure altruist' utility is modeled as a convex combination of the group payoff and the individual's private payoff. Since the group payoff is held constant when an individual contributes her endowment regardless of her choice of time, not immediate contributions cannot capture the "altruism effect".

[31] The warm-glow effect measures the additional utility that a subject gains solely from the act of contribution (from being nice to other subjects) (Andreoni 1989,1990). Thus, if a warm-glow effect existed, it would only play a role on the decision of

3.2.3 Exogenous Risk

It was cited above that the tie-breaking rule in the tournament game is such that players contributing at same time share the subsidies equally in expected terms. The way in which ties are broken can be implemented experimentally either by (i) the introduction of a lottery[32] or (ii) the allocation to each player of the average of the rank payoffs. For example, if $\delta = (90, 70, 20, 0)$ and three players tied for first rank: (i) under the lottery method, the three players would participate in a simple lottery $L = \left(\frac{1}{3}, \frac{1}{3}, \frac{1}{3}\right)$, where the set of all possible subsidies is $\Delta = \{90, 70, 20\}$; (ii) under the average subsidy method, each player would each get paid the same subsidy $\bar{\delta_3} = (90 + 70 + 20)/3 = 45$. In a society consisting of risk-neutral and non-altruistic expected utility maximizers, both methods are strategically equivalent leading to the same theoretical predictions. Behaviorally, this difference might have an impact on contribution decisions because the lottery method makes of contributing a further "exogenously" risky alternative: gross contributing may result in one of a number of possible subsidies rebated but which subsidy will be earned by the player is uncertain at the time she must make a choice. It is also possible that subjects do care about fairness and show inequality aversion. These tastes that they bring from outside of the experiment might influence their behavior in the experiment.

3.3 The Hybrid Lottery

In the previous section, we proved that the RTSS could be successful in promoting the provision of the public good through an artificially generated negative externality created via competition among contributors to get the higher rebates. This competition helped to increase the private marginal benefit obtained from gross contributing the total endowment over its opportunity cost.

A different method to generate the same effect is through implementing a subsidy *rate* which is independent of the time profile and negatively dependent on the total level of gross contributions to the public good. To see this, let the total subsidy obtained by any given player i be: $s_i(k,t) = s(k_i + \sum_{j \neq i} k_j) \cdot k_i \; \forall i$, where $s(\cdot) \leq 1$ is the subsidy *rate* earned by every individual and it is a function of solely the total level of gross contributions: $K \equiv \sum_{j=1}^{N} k_j$. The total (opportunity) cost associated to the subsidies rebated is $\sum_{i=1}^{N} s_i(k,t) = \sum_{i=1}^{N} s(k_i + \sum_{j \neq i} k_j) \cdot k_i = s(K)K$, which is clearly endogenous. This scheme is budget balancing. The key property shared by both the hybrid lottery and the RTTS mechanisms is that an endoge-

whether or not to gross contribute the endowment but it would play no role on the timing of contribution decision

[32] The computer randomly assigns a rank to each player in a tie for a particular rank, being each player allocated the same probability of ending up in each of the possible ranks.

nous (weakly) *decreasing percentage* of total gross contributions is instantly rebated to gross contributors. In addition to the standard positive externality on all agents, any gross contribution made by an individual exerts a negative externality on the other gross contributors by decreasing their expected private payoff through an increase in the opportunity cost via a lower subsidy rate. Relative to the VCM, these schemes induce a greater private benefit from gross contributing by decreasing the marginal cost by more than the marginal gain. As a result, this compensating negative externality serves to overcome the free-rider problem. An additional desirable property of the hybrid lottery is its equity: all contributors earn the same subsidy rate.

The necessary condition for any player i to be willing to contribute w instead of refraining from contributing is:

$$s(w+K_{-i})w+\gamma\left(1-s(w+K_{-i})\right)(w+K_{-i})\geq w+\gamma\left(1-s(K_{-i})\right)K_{-i}$$

This condition can be rewritten as:

$$\gamma\left[\left(1-s(w+K_{-i})\right)w+\left(s(K_{-i})-s(w+K_{-i})\right)K_{-i}\right]\geq\left(1-s(w+K_{-i})\right)w \tag{3}$$

It states that the opportunity cost of gross contributing w to the public good for a contributor (given by the right hand side of the inequality) cannot exceed the marginal gains obtained from her contribution (given by the left hand side). A necessary condition for its satisfaction is $s(K_{-i})\geq s(w+K_{-i})$[33], that is, the subsidy rates should be decreasing in the total gross contribution level. Under this mechanism, the (marginal) contributor is net contributing $g_i(k)=w\left(1-s(w+K_{-i})\right)$ to the public good provision. However, her contributing decision exerts a negative externality on all other contributors through a decrease in the subsidy rate earned by them. As a result, the public good provision is increased furthermore: $\Delta G(k)=g_i(k)+\Delta G_{-i}(k)$ where $\Delta G_{-i}(k)=\left(s(K_{-i})-s(w+K_{-i})\right)K_{-i}\geq 0$. Hence, the (marginal) contributor is effectively net contributing $(g_i(k)+\Delta G_{-i}(k))$ to the public good while this net contribution costs her only $g_i(k)$, a lower amount. This condition can be expressed as $\Delta G_{-i}(k)\geq\left(\frac{1-\gamma}{\gamma}\right)g_i(k)$ and it is essentially our previous condition (1).[34] This condition specifies an upper bound for the subsidy rate function if level of contributions by others is sufficiently high: $s(w+K_{-i})\leq s(K_{-i})-(\alpha(K_{-i})-1)(1-s(K_{-i}))$ if $K_{-i}>\left(\frac{1-\gamma}{\gamma}\right)w$, where $\alpha(K_{-i})=\frac{1}{1-\left(\frac{1-\gamma}{\gamma}\right)\left(\frac{w}{K_{-i}}\right)}$[35]. Contributing w can be made a weakly dominant strategy for any agent

[33] The inequality must be strict if $s(w+K_{-i})<1$.

[34] The equivalence is $\delta_{\frac{\bar{K}_{-i}}{w}+1}=s(w+K_{-i})w=w-g_i(K)$ and $\delta_{\frac{K_{-i}}{w}+1}=s(w+K_{-i})(w+K_{-i})-s(K_{-i})K_{-i}=w-\Delta G(k)$.

[35] If $K_{-i}<\left(\frac{1-\gamma}{\gamma}\right)w$, then it must be satisfied that $s(w+K_{-i})=s(K_{-i})=1$ whereas if $K_{-i}=\left(\frac{1-\gamma}{\gamma}\right)w$, then it is necessary

if the subsidy function is designed such that condition (3)[36] is satisfied for all possible values of K_{-i}. A necessary condition is $s(0) = s(w) = 1$. On the other hand, the first best public good level can be obtained by setting the subsidy rate earned by all contributors equal to zero: $s(Nw) = 0$.

Proposition 3.4. *Under the Hybrid Lottery, there always exists a subsidy scheme such that gross contributing the entire wealth endowment is a weakly dominant strategy for all players and such that the private provision of the public good induced by the scheme is the (first-best) socially optimal level.*

Proof. Consider the following subsidy rate scheme $s(K) = 1$ if and only if $K \leq (N-1)w$ and $s(Nw) = 0$. This scheme satisfies condition (3) for all K_{-i}. As a result, contributing the endowment is always an optimal strategy for any agent regardless of her peer's strategies. If all agents contributed their endowment, the subsidy rate earned by each of them would be null and the first-best public good provision level would be attained. $\square$

If $\gamma < \frac{1}{2}$, the higher the value of the MPCR, the shorter the range of the total gross contributions for which the subsidy rate must be equal to one and the smaller the set of partial contribution Nash equilibria. If $\gamma > \frac{1}{2}$, then a subsidy rate function can always be found such that contributing is a weakly dominant strategy and the only Nash equilibria are the FCE and the ZCE. [37].

The theoretical analysis suggests testing the following hypothesis:

Hypothesis 3.4. *The Hybrid Lottery (HL) is a superior fundraising method to the standard VCM in terms of public good provision. The total number of contributors and the aggregate level of net contributions to the public good are significantly higher under the hybrid lottery than under the VCM.*

that $s(K_{-i}) = 1$. Note that $\alpha(K_{-i})$ is greater than one and a strictly decreasing and convex function of K_{-i} over the range $K_{-i} > \left(\frac{1-\gamma}{\gamma}\right) w$.

[36] If the strategy space of each agent is expanded and made continuous so that $k_i \in [0, w]$, the first order condition of any player i's problem is $\left(\frac{\gamma}{1-\gamma}\right) K_{-i} - h_i(k_i^*, K_{-i}) \geq 0$ (with equality if $k_i^* > 0$), where $h(k_i, K_{-i}) \equiv k_i + \frac{1-s(k_i+K_{-i})}{\left(-\frac{\partial s(k_i+K_{-i})}{\partial k_i}\right)}$. Note that $k_i^* = 0 \ \forall i$ is always an equilibrium. If $\gamma \leq \frac{1}{2}$ and the subsidy rate is everywhere convex or linear, then contributing zero is a strictly dominant strategy. If $h(0, k_{-i}) < \left(\frac{\gamma}{1-\gamma}\right) K_{-i}$ and the subsidy rate is everywhere "sufficiently concave" (so that $\frac{\partial h(k_i, K_{-i})}{\partial k_i} < 0$), then contributing w is a weakly dominant strategy. If $h(0, K_{-i}) < \left(\frac{\gamma}{1-\gamma}\right) K_{-i}$ and the subsidy rate is either everywhere "not sufficiently concave" (so that $\frac{\partial h(k_i, K_{-i})}{\partial k_i} > 0$), then contributing w is a weakly dominant strategy as long as $h(w, K_{-i}) \leq \left(\frac{\gamma}{1-\gamma}\right) K_{-i} \ \forall K_{-i}$. Finally, if $h(0, K_{-i}) > \left(\frac{\gamma}{1-\gamma}\right) K_{-i}$, the subsidy rate is everywhere "sufficiently concave" and condition (3) is satisfied for all possible values of K_{-i}, contributing w is a weakly dominant strategy.

[37] For example, assume $N = 4$ and $\gamma = \frac{3}{5} > \frac{1}{2}$. Consider the following subsidy rate function: $s(0) = s(w) = 1$; $s(2w) = \frac{2}{3}$; $s(3w) = \frac{1}{3}$ and $s(4w) = 0$. It generates only the following Nash equilibria: the efficient FCE and the ZCE. Furthermore, contributing is a weakly dominant strategy for every individual.

Our A(verage) and C(ertain) treatments refer to this scheme. Gross contributing the entire endowment is a weakly dominant strategy in the C(ertain) treatment but it is not in the A(verage) treatment.

3.3.1 Meaningful Comparisons

Some comparisons can be performed relative to other mechanisms suggested in the literature such as (fixed-prize and pari-mutuel) lotteries (Morgan(2000)) and last-price all-pay auctions where all the players pay the lowest bid (Orzen 2008). In order to perform the theoretical comparisons, we relax the assumption of an indivisible wealth endowment.

Hybrid Lottery vs. Pari-Mutuel Lottery or flat subsidy schemes. The prize is made endogenous under both mechanisms. Morgan (2000) states that the pari-mutuel prize structure “dilutes" the negative externality effects of a fixed-prize raffle since it introduces an additional positive externality (the increase in the prize pool following bets). Therefore, he concludes that it is less effective at providing public goods than its fixed-prize counterpart. We claim that this result is not due to the endogeneity of the prize amount but to its linear structure. The main difference among these two mechanisms is that the total amount rebated to contributors is linear in the total gross contribution to the public good in a pari-mutuel lottery. A flat subsidy rate implies that the elasticity of the subsidy rate with respect to the total gross contribution level is zero. Condition (3) is violated if the subsidy rate is lower than one. Instead, a *decreasing percentage* of total gross contributions is rebated in the form of “prizes" under the hybrid lottery, allowing the satisfaction of condition (3).

Hybrid Lottery vs. Fixed-Price Lottery. The expected payoff to any player who participates in a fixed-prize lottery is given by: $u_i(k_i, K_{-i}) = w - k_i + \left(\frac{k_i}{k_i+K_{-i}}\right) R + \gamma(\sum_{j=1}^{N} k_j - R) = w - \left(1 - \frac{R}{k_i+K_{-i}}\right) k_i + \gamma(\sum_{j=1}^{N} k_j - R)$ where R is the fixed-prize set apart from gross contributions to the public good. The effective individual subsidy rate is $s(k) = \frac{R}{k_i+K_{-i}}$. Hence, both mechanisms share the feature that the subsidy rate is decreasing in the total gross contribution level. But since the prize pool is made endogenous and not fixed under the hybrid lottery, we are adding an extra marginal contribution effect which is not taking into account in the fixed prize lottery:

$$\frac{\partial u_i}{\partial k_i} = (-1+\gamma) + \left\{ s(K) - \left(-\frac{\partial s(K)}{\partial K}\right) k_i \right\} + \gamma \left\{ -s(K) + \left(-\frac{\partial s(K)}{\partial K}\right)(K) \right\} = \tag{4}$$

$$-(1-\gamma) + s(K)\left(1 - \varepsilon_{s(K),K}\frac{k_i}{K}\right) + \gamma s(K)(\varepsilon_{s(K),K} - 1) = MB_{VCM} + \Delta_{lottery} + \Delta_{extra}$$

where $\varepsilon_{s(K),K} \equiv -\frac{\partial s(K)}{\partial K}\frac{K}{s(K)}$ is the elasticity of the subsidy rate with respect to the total gross contribution level. The first term corresponds to the "standard" marginal private benefit from voluntarily contributing one extra dollar, which is negative. The second term refers to "fixed-prize lottery effect" per se. The lottery increases the private benefit of contributing one dollar extra marginally ($\Delta_{lottery} > 0$) via a decrease in the private marginal cost of contribution. The cost to the agent of contributing one extra dollar is lower due to the subsidy rebated: $1 - s(K) < 1$. However, contributing one extra dollar has an impact on the total amount of subsidy obtained through a decrease in the subsidy rate. Hence, the contribution of an extra dollar raises the opportunity cost of the amount of money already contributed by agent i by $\left(-\frac{\partial s(K)}{\partial K}\right)k_i$. The fixed-prize lottery per se does not change the private marginal gain from contributing one extra dollar because the total amount rebated in form of subsidies is held fixed (ie. $\varepsilon_{s(K),K} = 1$). Therefore, the public good provision is increased by the extra dollar which is associated with a private gain of γ. Note that under the fixed-prize lottery, the effect of the decrease in the opportunity cost is linear in the prize pool. The greater is the prize pool, the greater is the marginal private benefit of contributing an extra dollar and the more of the wealth endowment are agents induced to bet in equilibrium[38]. By setting a sufficiently large prize pool, the fixed-prize lottery effect could be sufficiently great to overcome the negative private marginal benefit of the standard VCM. But given that the prize pool must be strictly positive and sufficiently large to induce the appropriate incentives, the first-best level of public good provision is not attainable.

The hybrid lottery has a similar impact as the fixed-prize lottery on the marginal cost of contributing but it also has an additional impact on the marginal gain from contributing because the total subsidy amount rebated to agents is not assumed fixed, that is, $\varepsilon_{s(K),K} \neq 1$. On one hand, from the extra dollar contributed, only $1 - s(K)$ is destined to increase the public good provision since the subsidy rebated $s(K)$ is spent on private consumption by the agent. On the other hand, the decrease in the subsidy rate increases the opportunity cost of the amount of money already contributed not only by agent i but by all other agents so that the public good provision is increased by $\left(-\frac{\partial s(K)}{\partial K}\right)K = s(K)\varepsilon_{s(K),K}$.

The "lottery effect" is strictly positive if and only if $\varepsilon_{s(K),K} < \frac{K}{k_i}$ whereas the "extra effect" is strictly

[38] Apart from the equilibrium in which all bettors contribute zero (assuming no access to deficit financing), there exists a unique positive contribution equilibrium in which all bettors contribute $k_i^* = \left(\frac{N-1}{N^2}\right)\left(\frac{R}{1-\gamma}\right)$ if $R < \left(\frac{N^2}{N-1}\right)(1-\gamma)w$ and $k_i^* = w$ if $R \geq \left(\frac{N^2}{N-1}\right)(1-\gamma)w$ (wealth-constraints become binding). The public good provision and social welfare reach their maximum levels at $R = \left(\frac{N^2}{N-1}\right)(1-\gamma)w$: $G^* = \left(\frac{N}{N-1}\right)(N\gamma - 1)w$ and $W^* = \left(1 + \frac{(N\gamma-1)^2}{N-1}\right)Nw$.

positive if and only if $\varepsilon_{s(K),K} > 1$. The "overall effect" is defined as the sum of these two effects. Since $\frac{K}{k_i} \geq 1$, an elasticity just above one is always beneficial. By choosing carefully the subsidy rate function, we could guarantee that both inequalities are satisfied, providing greater incentives for contribution. [39]

Hybrid Lottery vs. Lotto. Morgan states that "...The prize structure of the lotto is hybrid, having both fixed prize and pari-mutuel components. The fixed prize components come from two sources, guaranteed minimum payouts regardless of ticket sales and prize money rolled over from previous drawings in which there was no winner. Once ticket sales for a lotto drawing exceed some threshold, the prize pool is augmented in pari-mutuel fashion with a fixed percent of the handle being added to the prize pool..." (Page 773). Morgan's conclusion is "...reducing the pari-mutuel component of the prize structure while increasing the fixed prize component (with no change in the odds) should also yield higher lotto revenues." (Page 774). The prize structure of the lotto shares with the hybrid lottery two properties: (i) the underlying subsidy rates earned by the contributors are nonlinearly decreasing in the total gross contribution level; and (ii) the prize amount is endogenous. But contrary to the hybrid lottery, the prize amount is weakly increasing in the handle. An elasticity of the subsidy rate with respect to the total gross contribution level lower than one implies a strictly negative "extra effect" and a lower "overall effect" (despite a greater "lottery effect").

Hybrid Lottery vs. Last-Price All-Pay Auction. Consider an auction for which it is common knowledge that all players attach the same value $R \in (0, Nw)$ to the object on sale. This auction takes place in a setting characterized by homogeneity, complete information and common valuations. We focus on a last-price all-pay auction, in which every bidder pays the lowest bid and the bidder who submits the highest bid wins the object ($g_j(k) = \underline{k}$ for every loser and $g_i(k) = \underline{k} - R$ for the winner where $\underline{k}$ is the lowest bid). If the lowest bid is such that the revenue generated is not sufficient to cover the cost of the prize, the auction is called off. This game has multiple Nash equilibria.[40] The profile characterized by each player bidding her wealth endowment is a Nash equilibrium. To see this, suppose that player i lowers her bid by submitting k_i such that $\frac{R}{N} \leq k_i < w$. The decrease in the gross contribution made by player i creates an externality: k_i becomes the lowest bid submitted and the price to be paid by

[39] The "overall effect" is increasing in the elasticity value of the subsidy rate if and only if $K_{-i} > \frac{1-\gamma}{\gamma} k_i$. The public good literature generally assumes $\gamma > \frac{1}{2}$ implying $\frac{1-\gamma}{\gamma} k_i < k_i$.

[40] For example, there are multiple Nash equilibria in which at least two players submit a bid strictly lower than $\frac{R}{N}$, calling off the auction. The zero-contribution equilibrium belongs to this set of Nash equilibria.

all players is reduced. This effect is in the same spirit as the one created by the hybrid lottery: a decrease in gross contribution levels increases the subsidy rate earned by contributors, decreasing the opportunity cost of contributing the endowment and decreasing the public good provision level even further. This deviation only lowers i's expected payoff since less of the public good is now provided and her chances of winning the object vanish. If she deviated by submitting a bid of $k_i < \frac{R}{N}$, then auction would be called off (as the revenue would be insufficient to cover the cost of the prize/object, leaving no surplus for public good provision) and her payoff would be lower since $(N\gamma - 1)\left(w - \frac{R}{N}\right) > 0$. Note that this symmetric equilibrium exists for all values of R and by making it arbitrarily small, the first best outcome could be approached. Furthermore, *in a last-price all-pay auction with complete information and under the assumption of homogeneous agents, a player's bid equal to her wealth endowment weakly dominates all her other bids.* This result is due to two properties of the auction. First, this mechanism lowers the marginal cost of raising a bid, which is strictly higher than the lowest bid, to zero. Second, the individual marginal benefit of raising the lowest bid (assuming no ties on this bid) is strictly positive $(N\gamma - 1 > 0)$ as long as this lowest bid is sufficiently high $(\underline{k} \geq \frac{R}{N})$. However, this result is not robust to the introduction of heterogeneity among agents, be it heterogeneity in income or in preferences.[41] For example, if there exists at least one player with $\gamma_i < \frac{1}{N}$, there does not exist any Nash equilibrium with positive public good provision under the last-price all-pay auction while it does exist under the hybrid lottery.[42]

Hybrid Lottery vs. Progressive Tax Schemes with Income-Tax Deductions. A usual practice by governments is to subsidize donations to specific public goods via income tax-refunds. Although individuals cannot opt out of this mechanism, it is instructive to perform the comparison with the previous schemes. Assume that gross contributions to the public good reduce income tax liabilities through a decrease in the income tax base. Each agent pays taxes based on her after gross contribution income level: $I_i^n = w - k_i$. The total subsidy amount received by the agent i is $S_i(k_i, t) \equiv \int_{w-k_i}^{w} t(I_i)dI_i$ and her net income-tax payments are $T(I_i^n) = T(w) - S_i(k_i, t)$ where $t(I)$ is the marginal tax rate and $T(I) \equiv \int_0^I t(I_i)dI_i$ for any $I \in [0, w]$. Due to the crowd-out result, there is no additional benefit of

[41] Goeree et all (2005) advocate for a (two-stage) lowest-price all-pay auction mechanism augmented with an entry fee and reserve price.

[42] As a numerical illustration, consider the case $N = 4$, $w = 100$ and $\gamma_j = \{\frac{1}{5}, \frac{3}{5}, \frac{4}{5}, \frac{4}{5}\}$ so that $\bar{\gamma} = \frac{3}{5}$. By designing the subsidy rate function such that $s(0) = s(100) = s(200) = 1$ and $s(300) = s(400) = 0$, then $n^* = \{0, 3\}$ and $G^* = \{0, 300\}$. That is, all but the individual with $\gamma_i = \frac{1}{5}$ gross contribute in equilibrium.

assigning the net tax payments directly to public good provision since the subsidy decreases both the opportunity cost of contributing and the marginal return of investing in the public good by the same proportion. Hence, we assume that the total net payments are transferred to the agents via a lump-sum subsidy which is the same for all players. Contrary to the lotteries, the negative externality exerted by player i's contribution on the other players is via a reduction in their lump-sum transfer.

The expected payoff to player i is:

$$u_i(k_i, K_{-i}) = w - k_i - T(w - k_i) + \frac{1}{n}\sum_{j=1}^{N} T(w - k_j) + \gamma \sum_{j=1}^{N} k_j$$

The first order condition is:

$$\frac{\partial u_i}{\partial k_i} = (-1 + \gamma) + \left(1 - \frac{1}{n}\right) t(w - k_i) = MB_{VCM} + \Delta_{deduction} \tag{5}$$

As the fixed-prize lottery, the income-tax deductions increase the private marginal benefit from contributing via a decrease in the private marginal cost of contributing. Since the tax scheme is progressive, the first dollar contributed is refunded at the highest rate. Hence, the key feature shared with the previously mentioned mechanisms is that player i's subsidy rate declines as the player's gross contribution increases. However, the critical difference is that the subsidy rate earned by player i does not depend on other player's gross contribution levels. As a result, player i's strictly dominant strategy is to gross contribute $k_i^* = w - t^{-1}\left(\frac{1-\gamma}{1-\frac{1}{n}}\right)$ where $t^{-1}(\cdot)$ is the inverse of the marginal tax rate function. If $t(0) \geq \frac{1-\gamma}{1-\frac{1}{n}}$, the Pareto-optimal outcome is attained but real-world governments would have a hard time in getting support to implement this tax-income scheme.

Testing experimentally the implications of these comparisons is relevant but it is not the scope of the present paper. This investigation is carried out in Sánchez Villalba et all (2011c).

4 Experimental Design and Predictions

The experiment was conducted at the LaTEX computer laboratory (University of Alicante, Spain) on October 2010, 7th and 8th using a collection of computers that are linked together in a network. A total of 144 participants were recruited from the pool of undergraduate students who were enrolled at the University of

Alicante and were allocated to sessions according to their time preferences.[43] No subject was allowed to participate in more than one experimental session.

We report data from 6 experimental sessions and 6 treatments, namely, A(verage), B(ase), C(ertain), D(ominant), E(xogenous) and VCM. Sessions lasted between 90 and 120 minutes. Participants were allowed into the lab according to their arrival time and they entered and freely chose where to sit. They were not allowed to communicate for the entirety of the session and could not see other people's screens.

At the beginning of each session, written instructions were distributed[44] and read aloud by the instructor. In order to ensure their correct understanding, the participants were asked to complete a "short quiz"Ċorrect answers and the rationale for them were provided by the instructor after a few minute. Participants then played two "trial" (practice) rounds whose outcomes did not affect their experimental earnings. After each of these stages the instructors answered subjects' questions in private. The experimental rounds (12 per treatment) were then played, and after that, subjects completed a questionnaire with information regarding personal data and the decision-making process they followed. Finally, each participant was paid an amount of money consisting of a fixed amount (1.50 €) and a variable component equal to the earnings obtained in a randomly chosen round from an urn with balls. The exchange rate used to translate experimental currency ("pesetas")[45] into money was

$$100 \text{ ``pesetas''} = 10 \text{ €} \tag{6}$$

and the average person was paid 14.48€.

In each session, the 24 participants were grouped into three 8-member matching groups, that remained fixed throughout the session. In each round, subjects in a matching group were randomly grouped into two 4-person groups[46].

Each experimental round consisted of three stages: **(1)** the "Scenario calculator", in which subjects could see how their hypothetical payoffs could be affected by her own choices and the choices of their fellow group members[47]; **(2)** the "Choice" Stage, in which participants simultaneously made a decision that would have

[43] Between four and six "reserve" people were invited to each session and some of them had to be turned down because the target number of participants (24 per session) was reached. Each one of them was paid the standard 5€ show-up fee before being dismissed.

[44] The instructions for the B(ase) treatment are included in AppendixB. The complete set of instructions is available from the authors upon request.

[45] This is the traditional "experimental currency" used in the LaTEX laboratory.

[46] The purpose of this matching technology is to avoid the possibility of reputation-building

[47] Subjects did not need to do any calculations as they were provided with a table listing the experimental earnings components

an impact on their experimental payoffs; and **(3)** the "Feedback" Stage, in which the subjects were provided some information about the round outcome.

In the "choice" stage a one-shot game was played. Each participant was endowed with $w = 100$[48] "pesetas" and had to allocate them to one of two possible "activities" (Y or Z) interpreted as *(Gross) Contribution* and *No Contribution*, respectively.Formally, $k_i \in \mathcal{K} := \{0, 100\}$, where k_i is the (gross) contribution decision of player i and it takes the value 100 (resp., 0) when she dedicates her entire endowment to activity Y (resp., Z). In some of the treatments, players also had to choose *when* to make their gross contribution. Formally, $t_i \in \mathcal{T} := \{1, 2, 3, 4\}$, where t_i is the moment in time at which player i dedicates her endowment to activity Y[49]

In the experiment, the variables were labeled neutrally: u_i as "Result", $w - k_i + s_i(k, t)$ as "Component A", and $\gamma G = \gamma \left(\sum_{j=1}^{N} k_j - \sum_{j=1}^{N} s_j(k, t) \right)$ as "Component B". In the experiment, the MPCR is set equal to $\gamma = \frac{3}{5} = 0.6$[50] and "Component B"$= 0.6 \cdot 400 - 0.6 \cdot$ (sum of components "A" of the members of the group). Instructions highlighted the fact that different subjects could get different levels of private consumption (component A) but value of the private provision of the public good (component B) was the same for every member of the group.

The participant's submission of her decision (k_i and t_i) ends the "Choice" Stage and it is then procced to the "Feedback" Stage, in which every participant was informed about her choices, her rank (if relevant), both her private and her public consumption, and her payoff for the round. At no stage was a subject given any information about the choices or outcomes of any other participant (at least not explicitly, though they could infer them in some scenarios).

By clicking on the "Continue" button, participants exited the "Feedback" Stage and moved on to the next round (if any was left). Rounds were identical to each other in terms of their structure (Scenario calculator, Choice and Feedback stages) and rules (payoff computations, matching protocols), but may have differed in the *realised* values of the random variables (allocation of subjects to groups and tie breaking results). Participants were told this explicitly and that rounds were independent from each other.

associated to each profile in the instructions.

[48] Therefore, $Nw = 400$.

[49] Non-contributors were also asked to submit a time period although their timing decisions were irrelevant for the computation of the round outcomes.

[50] Consistent with the values frequently used in the literature –for example, Andreoni (1988) uses 0.5 and Morgan and Sefton (2000) use 0.75.

4.1 Treatments and Associated Risks

As specified in the theory section, treatments are characterized by different subsidy functions which involve various degrees of exogenous and endogenous risk. The subsidy functions are designed such that there exists a unique Nash equilibrium (the ZCE) in treatments VCM and E while there exist two Nash equilibria (the FCE and the ZCE) in treatments A, B, C and D. The multiplicity of equilibria raises a coordination problem in the latter treatments. Nevertheless, the FCE Pareto-dominates and risk-dominates[51] the ZCE. It is important to mention that the analysis holds not only for risk neutral players but also for risk averse players with a Constant Relative Risk Aversion ($CRRA$) utility and index of risk aversion r as high as 1.[52] Hence, both refinement criteria select the FCE over the ZCE as the unique predicted outcome of the game. Furthermore, gross contributing the endowment is a weakly dominant strategy for every player in treatments D and C. The use of weakly dominated strategies is unappealing and several refinement criteria, such as the iterative deletion of weakly dominated strategies or trembling-hand perfection, rule out its choice.

The maximum amount of total subsidies payable to the subjects remains constant and equal to 180[53] pesetas across treatments A, B, C and D. This implies that the ex-ante difference in earnings for a subject who goes from contributing all her endowment to contributing none of her endowment when everyone else contributes her endowment is identical regardless of whether subjects are in treatments A, B, C or D. Furthermore, since in all four treatments the prediction of the model is that the FCE will be selected, we can expect that the actual amount paid out in terms of subsidies will be exactly 180 per group. Thus, we can determine which treatment is better by simply comparing the number of gross contributors and the level of aggregate net contributions associated to each of them.

Although the only robust equilibrium in treatments A, B, C and D is the FCE, the behavioral response to the introduction of these incentive mechanisms might be different from predicted and very well dependent on the degree of exogenous and endogenous risk associated to the subsidy functions. By "exogenous risk" we

[51] Risk dominance is a criterion that reflects the risk (payoff loss) associated with deviating from an equilibrium: it selects the equilibrium which, if abandoned, yields the largest associated payoff loss. For example, in the case of treatment B, deviating from the FCE means switching from Y (that yields expected payoff 177) to Z (payoff=172). The associated loss is 177-172=5. On the other hand, deviating from the ZCE means switching from Z (that yields payoff 100) to Z (payoff=96). The associated loss is 100-96=4. Since the loss associated to the FCE is larger than the one associated to the ZCE, then the risk dominance criterion selects the FCE.

[52] According to Holt and Laury (2002), this should encompass about 75% of the population.

[53] It is equal to $90 + 70 + 20 + 0 = 180$ (in treatment B), $100 + 50 + 30 + 0 = 180$ (in treatment D), and $45 \cdot 4 = 180$ (in treatments A and C).

refer to the degree of variability in experimental payoffs among gross contributors (how disparate the subsidies received by the members of the group are). It is measured by computing the variance of the distribution of subsidies among contributors associated to the FCE (which is given by 1325[54] in treatments B and D and zero in treatments A and C). By "endogenous risk" (also referred to as "strategic risk") we refer to the risk of coordination failure on the FCE. It is measured by the minimum number of other contributors that makes of gross contributing the endowment any player's best response (for any number of other contributors equal or greater than that number). It is null in treatments C and D (because gross contributing the endowment is always a best response) and strictly positive in treatments A and B.

The following table classifies treatments A, B, C and D according to their degree of exogenous and endogenous risk:

		Endogenous Risk	
		Zero	Positive
Exogenous Risk	Zero	C(ertain)	A(verage)
	Positive	D(ominant)	B(ase)

(7)

FACTORIAL DESIGN

Similarly, the following picture depicts the different treatments on the Exogenous Risk–Endogenous Risk plane:

Treatments B and D (and respectively, A and C) share the same level of exogenous risk but the degree of endogenous risk is lower in D (respectively C) than in B (A). It is reasonable to expect that coordinating on the good equilibrium (FCE) is easier in D (C) than in B (A) because it is less demanding in terms of belief formation. By comparing the experimental contributions to the public good in treatments B vs. D and A vs. C, we could test the following hypothesis:

Hypothesis 4.1. ***Effect of endogenous risk:*** *Controlling for exogenous risk, the elimination of endogenous risk significantly increases the number of gross contributors and the net contribution levels toward the public good provision so that more of the public good is supplied.*

Similarly, treatments B and A (and respectively, C and D) share the same level of endogenous risk but B (D) has a higher (strictly positive) level of exogenous risk than A (C). It is reasonable to expect more willingness to participate in treatment A (C) than in treatment B (D) because of the lower variability in

[54] The variance associated to treatment B is computed as $\frac{1}{4}\left[(90-45)^2+(70-45)^2+(20-45)^2+(0-45)^2\right]$ and a similar computation is applied for treatment D.

payoffs. Thus, by performing a comparison of contributions in treatments A vs. B and C vs. D, we could test the following hypothesis:

Hypothesis 4.2. ***Effect of exogenous risk:*** *Controlling for endogenous risk, the elimination of exogenous risk significantly increases the number of gross contributors and the net contribution levels toward the public good provision so that more of the public good is supplied.*

Finally, we could also test the following hypothesis:

Hypothesis 4.3. *The degree of participation is a separable function of the level of exogenous and endogenous risk.*

The specific subsidy functions used in the experiment are:

- RTSS mechanism[55]:
  - Treatment B(ase)

$$s_i^B(k,t) = \begin{cases} 90 & \text{if } k_i = 100 \text{ and } Rank_i = 1 \\ 70 & \text{if } k_i = 100 \text{ and } Rank_i = 2 \\ 20 & \text{if } k_i = 100 \text{ and } Rank_i = 3 \\ 0 & \text{if } k_i = 100 \text{ and } Rank_i = 4 \text{ or if } k_i = 0 \end{cases} \tag{8}$$

The payoff table associated to this treatment (and all others) is listed in Appendix A. A player's best response is to contribute (Y) immediately if at least two other people in her group gross contribute their endowments (when three (resp. two) other people in her group contribute, then contributing pays her –in expected terms– 177 pesetas (resp. 132) while not contributing gets her only 172 pesetas (resp. 124)) and not to contribute otherwise (if $K_{-i} < 200$, she is better off not contributing because $106 > 104$ and $100 > 96$. This treatment exhibits a degree of endogenous risk equal to two according to our chosen measurement.

[55] *The adopted tie-breaking rule is as follows:* In case of a tie in the time of contribution, the computer randomly assigned a ranking position to each participant in the tie (each player having the same probability of being assigned each of the possible ranking positions). As an illustration, consider treatment B. if Player 1 ($P1$) contributed at $t = 1$, $P2$ and $P3$ at $t = 3$ and $P4$ did not contribute, then $P1$'s subsidy would be 90 –because she was the first to contribute– and $P4$'s subsidy would be 0 –because she did not contribute. $P2$ and $P3$ contributed at the same time and after $P1$, so they are "entitled" to subsidies 70 and 20 (corresponding to the second and third contributors). The tie breaking rule simply says that each one of them ($P2$ and $P3$) has the same chance of ending up getting each subsidy (20 and 70).

– Treatment D(ominant): contributing is a weakly dominant strategy for every player.

$$s_i^D(k,t) = \begin{cases} 100 & \text{if } k_i = 100 \text{ and } Rank_i = 1 \\ 50 & \text{if } k_i = 100 \text{ and } Rank_i = 2 \\ 30 & \text{if } k_i = 100 \text{ and } Rank_i = 3 \\ 0 & \text{if } k_i = 100 \text{ and } Rank_i = 4 \text{ or if } k_i = 0 \end{cases} \tag{9}$$

- Hybrid Lottery Mechanism: The subsidy function depends only on total gross contribution levels. It exhibits no exogenous risk since all gross contribution players receive the same subsidy amount.

  – Treatment A(verage)

$$s_i^A(k) = \begin{cases} 45 & \text{if } k_i = 100 \text{ and } K_{-i} = 300 \\ 60 & \text{if } k_i = 100 \text{ and } K_{-i} = 200 \\ 80 & \text{if } k_i = 100 \text{ and } K_{-i} = 100 \\ 90 & \text{if } k_i = 100 \text{ and } K_{-i} = 0 \\ 0 & \text{if } k_i = 0 \ \forall K_{-i} \end{cases} \tag{10}$$

  This subsidy function is closely related to the one specified for the B treatment. It was set equal to the average subsidies earned by gross contributors (given the above B treatment subsidy function) for each of the five possible values that the total gross contribution level can take. This implies that the ex-ante difference in earnings for a subject who goes from contributing all her endowment to contributing none of her endowment is identical in treatments A and B regardless of her fellows' actions. As in treatment B, contributing is a player's best response if and only if at least two players in the group gross contribute their endowments. Hence, the degree of endogenous risk is also two.

  – Treatment C(ertain): contributing is a weakly dominant strategy for every player.

$$s_i^A(k) = \begin{cases} 45 & \text{if } k_i = 100 \text{ and } K_{-i} = 300 \\ 60 & \text{if } k_i = 100 \text{ and } K_{-i} = 200 \\ 75 & \text{if } k_i = 100 \text{ and } K_{-i} = 100 \\ 100 & \text{if } k_i = 100 \text{ and } K_{-i} = 0 \\ 0 & \text{if } k_i = 0 \ \forall K_{-i} \end{cases} \tag{11}$$

  Similarly, this subsidy function is closely related to the one specified for the D treatment. It was set equal to the average subsidies earned by gross contributors for each of the five possible values that the total gross contribution level can take. The ex-ante difference in earnings for a subject who goes from contributing all her endowment to contributing none of her endowment is identical in treatments C and D regardless of her fellows' actions.

- ATSS: Treatment $E(xogenous)$ The subsidy function is:

$$s_i^E(k_i, t_i) = \begin{cases} 90 & \text{if} \quad k_i = 100 \text{ and } t_i = 1 \\ 70 & \text{if} \quad k_i = 100 \text{ and } t_i = 2 \\ 20 & \text{if} \quad k_i = 100 \text{ and } t_i = 3 \\ 0 & \text{if} \quad k_i = 100 \text{ and } t_i = 4 \text{ or if } k_i = 0 \ \forall t_i \end{cases} \tag{12}$$

  Unlike the previous cases, not contributing is a strictly dominant strategy for every player so there are not coordination issues. We only compare the E treatment to the B treatment because they share a similar structure (similar subsidy distribution). The comparison between E and the other treatments (A, C, D) can be done indirectly via the comparison between the E and B treatments on the one hand, and the comparison between B and the rest of the treatments on the other hand.

- Voluntary Contribution Mechanism Treatment

  This treatment is variation of the standard VCM game with a finite set of actions. Each player can choose among five possible discrete net contribution levels: $g_i \in \{0, 10, 30, 80, 100\}$. Note that in terms of public good provision, $g_i = 10$ is equivalent to player i gross contributing her endowment ($k_i = 100$) and earning a subsidy amount of 90 pesetas ($s_i = 90$). Hence, for comparison reasons, although this mechanism does not involve the use of subsidies, it might be useful to re-write it as if subsidies were available to the subjects. Thus, its subsidy function is:

$$s_i^{VCM}(k_i, a_i = \begin{cases} 90 & \text{if} \quad k_i = 100 \text{ and } a_i = 90 \\ 70 & \text{if} \quad k_i = 100 \text{ and } a_i = 70 \\ 20 & \text{if} \quad k_i = 100 \text{ and } a_i = 20 \\ 0 & \text{if} \quad k_i = 100 \text{ and } a_i = 0 \text{ or if } k_i = 0 \end{cases} \tag{13}$$

  where $a_i \in \{0, 20, 70, 90\}$ is the player's choice of "component A" (i.e., of private consumption). Thus, a player's net contribution is given by $g_i = k_i - a_i$ if $k_i = 100$ and $g_i = 0$ if $k_i = 0$.

In treatments E and VCM the model predicts the Zero Contribution outcome, and hence no subsidies paid in equilibrium. Valid comparisons between these two treatments can also be made in terms of number of gross contributors and aggregate net contributions, knowing that total spending on subsidies is the same in both treatments in equilibrium. It is easy to see that the subsidy functions shown in equations 12 and 13 are mathematically identical, the only difference being that the variable t_i in equation 12 was relabeled as a_i in equation 13. The economic interpretation also changed: in the first case the explanatory variable was the (absolute) moment in time at which the player chose to contribute; in the second one it is the choice of the player regarding the level of her component A (private consumption). Game theoretically, the change does not alter the properties of the game: no contribution remains a strictly dominant strategy. By testing hypothesis (3.1), we are really testing for framing effects (relevance of the absolute time dimension).

Finally, the comparison between the first four cases (A, B, C, D) and the last two (E, VCM) is less direct because the subsidies paid out in equilibrium are quite different. To overcome this problem, we compute the number of gross contributors on one hand and the aggregate net contributions as proportions/ratios of their maximal attainable levels[56] on the other hand, and make the comparisons based on these so computed variables.

5 Experimental Findings

A total of 1728 observations were collected in the experiment. There are two variables of interest for our analysis:

1. the level of net contributions per capita (or, equivalently, the amount of public good consumed by each member of the group) $\frac{G}{N} = \frac{1}{N}\sum_i g_i$, and
2. the level of gross contributions per capita $\frac{K}{N}$.

The two of them are related as follows:

$$\frac{G}{N} = \frac{K}{N} \times \frac{1}{K}\sum_i g_i$$

i.e., the level of net contributions per capita $\left(\frac{G}{N}\right)$ is the product of two factors: the proportion of people in the matching group who contributes $\left(\frac{K}{N}\right)$ and the level of net contributions per contributor $\left(\frac{1}{K}\sum_i g_i\right)$.

[56] Given the distribution of subsidies, the maximal level of public good provision is given by $400 - 180 = 220$€in treatments A, B, C and D and by $400 - 0 = 400$€in treatments E and VCM.

Extrapolating this relationship to a large population, the ratio $\left(\frac{K}{N}\right)$ becomes the *proportion* of contributors in the population (or the probability that a given person contributes). Thus, the level of net contributions per capita can be interpreted as the product of two factors: the proportion of contributors and their (i.e., contributors') average net contribution.

5.1 E v VCM

The following diagram shows the public good provision generated by treatments E and VCM –as fractions of their respective first-best levels– over the 12 rounds of the session. The session rounds are displayed on the horizontal axis, while the public good provision is shown on the vertical axis and ranges from 0 (no provision) to 1 (first-best provision).[57]

Both the graphical and econometric analyses confirm that E and VCM yield the same results in terms of public good provision (Wilcoxon-Mann-Whitney independent samples test, *z=0.1340*, *P=0.4483, two-tails*). Thus, hypothesis **??** is not rejected and, as a consequence, we conclude that introducing time per se is *not enough* to improve the performance of the VCM. In other words, the *framing* of the problem (as a standard VCM or as a mechanism with $ATSS$) is **not** relevant in this case. In general, this means that the introduction of a second dimension in absolute terms on which to base the level of subsidies paid to contributors has no significant impact on the provision level of the public good since the game continues to be a prisoner's dilemma. Rather, the actual way in which this second dimension determines the value of subsidies is crucial (as will be shown below).

Before moving to the next hypothesis, it is important to notice that, unlike in other VCM experiments, the behaviour of contributions does not decrease from about 50% in the first period to about 20% by the last round (Isaac and Walker (2008), Holt and Laury (2008)). Rather, average net contributions in both treatments are rather stable over the 12 rounds, showing little variance around the mean (around 20%). The explanation for this situation, thus, only needs to address the fact that contributions are significantly lower than 50% in the first period, since the convergence towards and stabilisation around 20% is indeed observed in our data. Indeed, it can be said that, if anything, our results simply "sped-up" the convergence process. This "faster convergence" result can be explained by two main factors related to the design of the experiment:

[57] The same information is shown in all subsequent diagrams, namely, session rounds on the horizontal axis and public good provision (as percentage of first-best provision) on the vertical one.

1. Before and during the experimental rounds, subjects had the possibility of (a) answering a few quiz questions to test their understanding about the mechanics of the game, (b) playing some trial rounds, and (c), most importantly, before *each* of the 12 experimental rounds of the session, subjects could use the "scenario calculator" to see how different combinations of their own and their fellow group members' contributions affected their payoffs.

2. Unlike other experiments, our VCM and E treatments significantly restricted subjects' contribution choice. In particular, subjects could choose one out of only 5 alternatives, namely, not contributing, contributing 10 (if done in the first period), contributing 30 (if done in the second period), contributing 80 (if done in the third period), and contributing 100 (if done in the fourth and last period). In most VCM experiments (e.g., Saijo (2008), Dorsey (1992)) subjects are endowed with some wealth that they can allocate between contribution and no-contribution with a large degree of freedom.[58] This means that, among all possible contributions, subjects *could* choose to contribute about half of their endowment in the first period. This is not possible in our setting, and we deliberately chose it so. The rationale behind our design choice is that 50 is clearly a focal point that subjects could coordinate on (it corresponds to half of their endowments), and we did not want to encourage such "psychology-led" decision-making process. Rather, we wanted them to make a more informed and thoroughly-thought decision. Thus, subjects could not just play "wait and see" by contributing 50, but they had to choose, say, between the closest options: either contributing 30 or contributing 80. We conjecture that proximitiy and/or risk aversion lead most people to choose the 30 option in the first round, and from then on, the usual convergence to the 20% benchmark occurs.

5.2 E v B

From the diagram (and the econometric evidence), it can be seen that the public good provision is higher in the Base treatment than in the Exogenous one in all rounds (Wilcoxon-Mann-Whitney independent samples test, *z=-2.2372, P=0.0125, one-tail*). Thus, hypothesis **??** cannot be rejected, so that one could argue

[58] Usually contributions are not considered as continous variables, but the lowest amount that a subject can contribute is rather small compared to the amount of wealth the subject is endowed with. For example, Saijo (2008) gives subjects 24 units of experimental currency each round and the minimal contribution is 1 unit.

that mechanisms based on the relative timing of contributions ($RTSS$) are superior to those based on the absolute timing of contributions ($ATSS$). Furthermore, from the result in the previous sub-section, the Base treatment is also better than the standard Voluntary Contribution Mechanism (Thus, hypothesis **??** cannot be rejected). The economic rationale behind this result stems from the negative externality generated by the competition to be the first contributor in the Base treatment. Said negative externality narrows the gap between social and individual marginal benefit via increasing the private marginal benefit by the amount of the subsidy received.[59]

Note that the level of public good provided in the Base treatment is quite close to the first-best provision in the first round, and then it goes down, finishing at around 50% of the first-best level. This seems to be the result of some kind of "disappointment" felt by some players, whose expectations may have been to coordinate in the "good" (full-contribution) equilibrium, so that they contributed all their wealth only to find out that nobody/not everybody else contributed all of theirs, and so decided to (at least partially) free ride in subsequent rounds.

5.3 B v D

Neither the graphical nor the econometric analysis show a significant difference between the results of the Base and Dominant treatments (Wilcoxon-Mann-Whitney independent samples test, *z=-0.4845*, *P=0.3156, one-tail*). Thus, hypothesis 4.1 is rejected, which seems to imply that endogenous risk does not affect players' choices. This is especially surprising because in B players face a coordination game (hence risk of coordination failure is quite high) while in D full contribution is a weakly dominant strategy.

A possible explanation is related to the idea of complexity, though since both treatments have identical rules and only differ in a few payoffs, it is difficult to support this idea unless one is willing to "blame" the pool of subjects. However, the fact the level of provision is rather stable at around 50% of the FB-level seems to indicate that people did not learn to play the game over time, despite the availability of a (weakly) dominant strategy.

An alternative may be risk aversion, but even people as risk averse as those with $r = 1$ should contribute all her endowment in D, and they do not.

[59] Actually, the gap between social and indivual marginal cost is also affected by the subsidy (because the money paid out as subsidies cannot be used to produce the public good), but this effect is smaller (in intensity) than the effect on the (social and private) marginal benefits, so the latter dominates.

Perhaps the result is due to the fact that people have other goals apart from getting the highest (expected) payoff. For example, some people may dislike competition, and so could prefer not to contribute rather than entering into one. Others may look for some "entertainment value" out of the experiment and so –facing a game that seems to have a unique and rather straightforward optimal strategy– would go for some variety and play different strategies (in this case, would not contribute sometimes).

Finally, it might be the result of some kind of cognitive (or in general, behavioural) constraint. This idea is probably related to the complexity argument, but might be better at explaining the "no-learning" result. It might simply be the case that people follow some basic rules of thumb that lead to decisions that do not always coincide with the ones that would be made by a fully-rational, perfect-forsight, Bayesian-updater individual. For example, it might be the case that people do not measure (exogenous) risk by computing the variance of the distribution, but they simply "count" good cases and bad cases (above and below a reference point) and then attach equal probability to each of these cases. Thus, if the reference point is, say, the average subsidy (45), then in both treatments there are two "good" possibilities (70 and 90 in B; 100 and 50 in D), and so the similarity of choices results. This is in line with the idea of "chance maximisers" in Sánchez Villalba (2010).

5.4 B v A

After a somewhat erratic beginning of the session, it can be seen that the Average treatment is better than the Base one (econometric analysis confirms this: Wilcoxon-Mann-Whitney independent samples test, z=2.2990, *P=0.0107, one-tail*). Thus, hypothesis 4.2 cannot be rejected, meaning that reducing the degree of exogenous risk is a good policy. This can be interpreted both in terms of risk assessment (less variability in the subsidy schedule) and of inequality assessment (less inequality in the population), and it is not clear which of the two interpretations is behind the result.

Also, since we found before that the *D*ominant and *B*ase yielded the same results, this means that the *A*verage treatment does better than the *D*ominant one, and so that exogenous risk seems to be more important than endogenous risk.

As an extra remark, this comparison between A and B treatments suggests that adding a second dimension to the subjects' decision problem (in particular, adding the time dimension in treatment B) does not necessarily increases (net) contributions. In fact, in this case, the 2-dimension treatment (B) performs worse than the 1-dimension one (A).

5.5 A v C

As seen in the diagram, there are no significant differences between treatments Average and Certain in terms of public good provision. This result is confirmed econometrically (Wilcoxon signed rank matched pairs test, T^{+}=*28, P=0.2852*) and is further evidence against hypothesis 4.1. The possible explanations for this behaviour are similar to the ones suggested in the comparison of B and D treatments (section 5.3). But the rejection of hypothesis 4.1 in this case is even more striking: the complexity and cognitive arguments are harder to sustain here. The "other goals" argument is still reasonable and we can risk another one: it might be the case that we cannot distinguish the two treatments simply because there is not much room for improvement beyond the Average treatment. In other words, the Average treatment is already performing so well (around 80% of the FB-level), that the Certain treatment has a hard time trying to improve upon A's performance.

Note also that (from the last three sections), it can be said that the Certain treatment fares better than the Dominant one in terms of public good provision, which strenghtens the support for hypothesis 4.2.

5.6 Discussion of experimental results

Summarising the experimental results of this section, one could order treatments in three groups:

1. The best ones are A and C, that are equally good and whose main feature is that exogenous risk is zero;

2. Second-best ones are B and D: the presence of exogenous risk decreases total net contributions compared to the previous two treatments;

3. Finally, the worst of them all, E and VCM: the absence of interrelation between my own subsidy and other people's subsidies lowers total net contributions compared to the intermediate treatments.

Thus, two main results can be obtained from this analysis:

1. *Interaction/externality* among players (not just the existence of a second dimension) is **crucial**; and

2. While exogenous risk seems to be very important, endogenous risk seems to be totally irrelevant for decisions.

As a consequence of the second result, if one were to draw an "iso-contribution" indifference map on figure **??** on page **??**, the "iso-contribution" indifference curves would probably be straight vertical lines[60] and contributions would increase in the east-west direction (supporting hypothesis 4.3).

6 Discussion

The key question is: what features should the second dimension have for the results to hold? Basically two:

1. Is must be a dimension that can be *ordered*. This may seem to restrict our choices to quantifiable/measurable variables, thus discarding qualitative dimensions. This is not the case in many situations, as apparently qualitative dimensions can be "quantified." For example, "colour" (green, red, blue, etc.) seems to be a qualitative variable, but can be "quantified" according to their wavelengths –furthermore, colours can be "ordered" in exactly the same way by simply replicating the rainbow pattern. And note that the way in which they are ordered (say, from longer to shorter wavelength or viceversa) does not matter at all. All that is needed is to be able to order them in *some* way. Furthermore, it can be an absolutely *arbitrary* order (say, first orange, then blue, then violet, etc.).[61]

2. It must be a dimension that does not lead to *ambiguity* (in the experimental sense). That is, a person's choice (regarding the second dimension) should not depend on some unobserved characteristics of the (potential) contributors (e.g., ability). This is the reason why we did not design the experiment in *real time*, but rather asked people to *choose* their time of contribution out of four options (from first to fourth period). If we had used a real time stage game, faster people would have an advantage over slower people but, more importantly, each player should *estimate* her own speed **and** the "speed distribution" of the population. Thus, observations would have conflated two effects: the "true" choice (as in our experiment) and the "ambiguity" effect (that would have resulted from each player trying to estimate the "speed distribution" of the population and her own relative position in it).

[60] Clearly we cannot affirm that indifference curves would be vertical straight lines because we only have four observations (two on each curve), but the previous results do seem to support the possibility of vertical "iso-contribution" curves.

[61] Another variable that seems to be purely qualitative is "sex," and yet it can be easily quantified by, say, counting the number of "x" (or "y"!) chromosomes. Gender, on the other hand, is not easily quantified, but can still be ordered (in any way, even entirely *ad hoc* ones).

7 Extension: Heterogeneity

The basic mechanism can be extended in several ways. We will focus on this section on the effect of heterogeneity. In all extensions we will assume that everyone receives the same subsidy (i.e., similar to cases Average and Certain) as this ensures an equitable mechanism.

A factor that may influence our results is the fact that we forced every player to be identical to each other.[62] So, here we explore what could happen if we relaxed the homogeneity assumption. In order to do so, we focus on two possible sources of heterogeneity: differences in wealth and differences in preferences. For simplicity, we analyze each case in isolation (i.e., we introduce differences in wealth among players, but keep the assumption of homogeneous preferences). The extrapolation to the case in which both sources of heterogeneity are present is rather straightforward, but requires modeling the relationship between wealth and preferences (formally, the joint probability distribution of the two variables), which is beyond the scope of the present paper and extension.[63]

7.0.1 Wealth heterogeneity

Consider the case in which there are 4 people, two of them are "rich" (their endowment is $w_R = 150$) and the other two are "poor" (their endowment is $w_P = 50$). Note that total wealth in the economy W is still 400 pesetas, so that the only thing that changes is the income distribution. Poor people can choose whether to contribute everything (50) or nothing (0) while rich people can contribute in multiples of 50 (50, 100 or 150) or zero (0). The subsidies are now based on the minimum possible contribution (in this example, 50), so that we have to determine subsidies for the cases in which contributions are 0, 50, 100, 150, 200, 250, 300, 350 and 400 pesetas.

[62] If everyone is homogeneous , the first-best outcome can be (almost) achieved by using as funding mechanism either: (i) a last-price all-pay auction (LPA, Orzen, 2008) by setting the prize arbitrarily small; or (ii) a lowest-common denominator mechanism, identical to LPA but with no prize, as in VCM. The FCE is no longer unique in the latter case (in fact, a continuum of equilibria exists in this case) but contributing the entire endowment is a weakly dominant strategy.

[63] This is an avenue that we, however, would like to explore in the future. By making the correlation between wealth and preferences vary, we can investigate which of the two types of heterogeneity is more important and under which circumstances. Further, it would be important to estimate empirically the joint distribution of the two variables using real (not just experimental) data.

The FB is again *feasible* in several cases, as for example in the tables shown in figure **??**, in which the subsidy function is such that the $s(0) = 0$, $s(50) = s(100) = s(150) = s(200) = s(250) = s(300) = s(350) = 50$, and $s(400) = 0$. That is, subsidy equals the gross contribution in all cases except when everyone contributes all their wealth. It can be seen that both the rich and the poor people consider contributing as weakly better than not contributing (strictly better if everyone contributes all their wealth) and that in the FCE the subsidy is *zero* for everyone.

There are many other subsidy functions that implement the FB FCE, so we can conclude that our assumption regarding homogeneity of income is not problematic since *our mechanism can still implement the FB FCE even when the wealth distribution is not degenerate.*

7.0.2 Heterogeneous preferences

Consider now the case in which players have the same wealth ($w = 100$ each) but they differ in their preferences. The preferences are indexed by the parameter γ, the marginal per capita return (MPCR). For example, let us assume there is one person with $\gamma_{low} = \frac{2}{5}$, two people with $\gamma_{medium} = \frac{3}{5}$ and one person with $\gamma_{high} = \frac{4}{5}$, so that the average MPCR is $\gamma := \frac{1}{N}\sum_{i=1}^{N}\gamma_i = \frac{3}{5}$. Note that every person has an MPCR lower than 1, so without a subsidy each player's optimal (actually, strictly dominant) strategy is not contributing anything. At the same time, since the average MPCR is greater than $\frac{1}{N} = \frac{1}{4}$, the socially optimal strategy is for every person to contribute all their endowment. The payoff tables would look like the ones shown in figure **??**, in which the subsidy function is such that the $s(0) = 0$, $s(100) = s(200) = 100$, $s(300) = 75$ and $s(400) = 0$.

As can be seen, for every type of player (as defined by the preference parameter γ), contributing is the weakly dominant strategy. Further, the first best is feasible: everyone will net contribute all their income (the subsidy when everyone gross contributes their endowment is equal to *zero*). Thus, our mechanism can deal with the presence of heterogeneity in preferences.

8 Conclusions

The private provision of public goods is one of the fundamental topics of Public Economics and has ample application to many real-world situations. Indeed, the presence of public goods is one of the sources of market failure: when left alone, the private market will provide an inefficiently low level of provision of public goods. Examples of this problem can be found in many scenarios, from the low level of charity giving in a society or of foreign aid among states, to the low effort exerted by workers when paid according to the team output, to the under-investment in private vigilance in a neighborhood, to many others.

The underlying problem behind all of this situations is always the same: the clash between social and individual objectives: while the socially optimal action is to contribute, the individually optimal action is to "free-ride". Several studies have considered different alternative methods designed with the objective of eliminating (or at least mitigating) the inefficiency associated with the private provision of public goods. From pricing strategies (Lindahl), to truth-telling mechanisms (Groves-Ledyard), to alternative settings (provision points, money-back guarantees, lotteries *à la* Morgan), to a long list of etceteras.

The mechanism we propose in this paper is based on the same idea than Morgan's (2000) paper, namely, introducing a negative externality among the individuals that (partially) offsets the positive externality present in the voluntary contribution mechanism. Our goal was to contribute to the area of voluntary contribution mechanisms (VCM) by formulating a theoretical model to predict the behavior of individuals when they have to decide not only if and how much, but also *when* to contribute to the public good provision. We proposed that contributors should get a "discount" or "subsidy" for early contribution and pay the full price otherwise. This could lead to some people –that may had not contributed at the non-discounted price– to contribute early in order to pay less.

Our mechanism is based on voluntary contributions and improves the performance of the best alternative (in terms of number of contributors and aggregate contributions) and yet it is simple (easy to implement and understand), cheap and self-financed (it is *never* needed to pour money into it from other sources). Furthermore, it can even generate an equitable outcome by paying the same subsidy to everyone.

The key feature of the mechanism is that it changes the nature of the game: the VCM Prisoners' Dilemma is transformed into a coordination game with two equilibria: one is the "bad" equilibrium in which nobody contributes (as in the VCM case) and the other one is the "good" equilibrium in which everybody contributes. If properly designed, the good equilibrium can then be selected by the two most popular criteria used to select an equilibrium in games with multiple ones, namely, the payoff-dominance criterion and the risk-dominance one.

Since early contributors get larger discounts than later contributors, then different people receive different discounts, which in turn raises the issue of the risk associated with the subsidy scheme. This type of risk we labeled "exogenous risk" because it is the direct result of offering different discounts to different people.

On the other hand, the existence of multiple equilibria in the coordination game implies that the risk of coordination failure on the Full-Contribution Equilibrium is something to take into account. We called this "endogenous or strategic risk" because it is the result of players' actions. Further, we could crudely measure the degree of endogenous risk by "counting" the minimum number of contributors in the economy that are needed to make my contribution a profitable path of action: if contributing is profitable only if everyone else contributes as well, then the risk of coordination failure (hence, the endogenous risk) is high, because one deviation is enough to make me change my decision and choose not to contribute instead.

We tested the theoretical predictions of the model using experimental data. Our hypotheses were such that we could order treatments in terms of their performance (number of contributors and net contributions per capita):

1. we expected treatments with lower levels of risk (exogenous or endogenous) to be better than those with higher levels of risk;

2. we expected treatments in which a person's subsidy depended on the actions of everyone to be better than those in which a person's subsidy depended only on that person's action.

Our empirical results strongly support the second hypothesis. This means, in particular, that our subsidy scheme is better than the standard VCM. Adding time (or any second dimension) is not enough to obtain our results: it is the negative externality generated by the interdependence of subsidies that is crucial.

The data also support the first hypothesis regarding the effect of exogenous risk, but reject it with respect to endogenous risk.

In summary, we designed a mechanism that is better than the alternative methods suggested in the literature: it produces a larger amount of public good (which is the efficient action to undertake in this setting) than alternative mechanisms, it is simple to understand by the potential contributors and it is easy and cheap to implement by the fundraiser (with special stress on the fact that it is an entirely self-financed mechanism). Furthermore, in some of their variants it can be shown to yield an equitable outcome (every person gets the same subsidy). On top of that, our preliminary results suggest that first best provision both in terms of number of contributors and size of contributions may be feasible under some conditions that we are trying to pin down precisely. Also, our preliminary results seem to indicate that the mechanism is robust to the introduction of heterogeneity (say, in terms of income or of the rate of transformation between private and public consumption) and of more general utility functions. All of these topics are part of our research agenda connected to this topic, as well as others including the issues that we could not cover so far like provision points or dynamic games.

We also showed experimental evidence that supports most of our hypotheses. Thus, the combination of a solid theoretical model and the supporting experimental evidence suggest that the mechanism we designed can be successfully implemented as a means to finance public goods through voluntary contributions, yielding results that are both efficient and equitable.

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A Payoff Tables

A.1 Treatment Base

The matrix of payoffs to player i is now:

$K_{-i} := \sum_{j \neq i} k_j$

		300	200	100	0
	0 (Z)	100 + 72 = 172	100 +24 = 124	100 + 6 = 106	100 + 0 = 100
	100 (Y1st)	90 + 132 = 222	90 + 72 = 162	90 + 24 = 114	90 + 6 = 96
k_i	100 (Y2nd)	70 + 132 = 202	70 + 72 = 142	70 + 24 = 94	
	100 (Y3rd)	20 + 132 = 152	20 + 72 = 92		
	100 (Y4th)	0 + 132 = 132			
	Average Y	45 + 132 = 177	60 + 72 = 132	80 + 24 = 104	90 +6 = 96

(14)

Payoff table. Base treatment

The payoff to the (row) player i when her choice is k_i (rows) and the other members of the group (gross) contribute K_{-i} pesetas (columns) is indicated in each cell. The first term is the private consumption (the subsidy if Y is chosen) and the second one is the utility associated to public good consumption. Note that when player i chooses Y, her final payoff (and her subsidy) depends on the ranking position of contribution (indicated by 1st^{oo}etc. on the row headers). The last line shows the average payoff to a contributor for each possible level of K_{-i}. This line was not shown to subjects (it was not listed in the instructions). By comparing this line to the first one, we conclude that if at least two of the other people in the group contribute, her unique best response is to contribute. On the contrary, if at most one other person the group contributes, her unique best response is not to contribute. As a result, there exist two Nash equilibria: the full contribution equilibrium (FCE) and the Zero contribution equilibrium (ZCE).

A.2 Treatment Dominant

The matrix of payoffs to player i is:

$$K_{-i} := \sum_{j \neq i} k_j \tag{15}$$

		300	200	100	0
	Z	$100 + 72 = 172$	$100 + 30 = 130$	$100 + 0 = 100$	$100 + 0 = 100$
	100 (Y1^o	$100 + 132 = 232$	$100 + 72 = 172$	$100 + 30 = 130$	$100 + 0 = 100$
k_i	100 (Y2^o	$50 + 132 = 182$	$50 + 72 = 122$	$50 + 30 = 80$	
	100 (Y3^o	$30 + 132 = 162$	$30 + 72 = 102$		
	100 (Y4^o	$0 + 132 = 132$			
	Average Y	$45 + 132 = 177$	$60 + 72 = 132$	$75 + 30 = 105$	$100 + 0 = 100$

Payoff table. Dominant treatment

A risk neutral player would now realize that choosing Y (i.e., contributing) is a weakly dominant strategy. Thus, there is no presence of endogenous risk: the only robust equilibrium is the FCE.

A.3 Treatment Average

The matrix of payoffs to player i is now:

$$K_{-i} := \sum_{j \neq i} k_j \tag{16}$$

		300	200	100	0
	Z	$100 + 72 = 172$	$100 + 24 = 124$	$100 + 6 = 106$	$100 + 0 = 100$
k_i	Y	$45 + 132 = 177$	$60 + 72 = 132$	$80 + 24 = 104$	$90 + 6 = 96$

Payoff table. Average treatment

Note that this table consists of the first and last row of the table of payoffs of treatment B (table 14). The analysis is, therefore, identical to the one developed immediately below that table, and so are the results: the game is a coordination game, it is optimal to contribute if and only if at least two other people in the group do so, and the FCE is the only robust equilibrium.

A.4 Treatment Certain

The matrix of payoffs to player i is now:

		$K_{-i} := \sum_{j \neq i} k_j$			
		300	200	100	0
	Z	$100 + 72 = 172$	$100 + 30 = 130$	$100 + 0 = 100$	$100 + 0 = 100$
k_i	Y	$45 + 132 = 177$	$60 + 72 = 132$	$75 + 30 = 105$	$100 + 0 = 100$

(17)

PAYOFF TABLE. CERTAIN TREATMENT

Note that this table consists of the first and last row of the table of payoffs of treatment D (table 15). Unlike treatment D, the subsidy does not depend on the timing of contributions but on total gross contribution levels. The corresponding analysis is identical to the one developed in treatment D and so are the results: contributing is now a weakly dominant strategy and the FCE is the only robust equilibrium.

B Instructions for treatment B[64]

INSTRUCCIONES

Introducción

Antes de empezar, muchas gracias por participar en este experimento. Es importante que sepas que, aunque forma parte de un proyecto de investigación serio, este experimento NO es un examen. No hay, por lo tanto, respuestas "correctas" ni "incorrectas". Igualmente, en todo momento, se preservará el anonimato de todos los sujetos participantes del mismo.

Cómo funciona el experimento

Primero que nada, te indicaremos las reglas básicas y te daremos las instrucciones necesarias. Luego pasaremos al experimento propiamente dicho, donde se te pedirá que tomes decisiones en una serie de situaciones que te presentaremos. Finalmente se te pagará: una parte fija por haber participado (1,50 €) y una parte variable que dependerá de tu actuación en las situaciones mencionadas anteriormente.

El experimento se compone de 6 secciones:

[64] Instructions for the other treatments were similar to these ones, with the logical changes in rules and parameters needed in each case.

1. Instrucciones
2. Mini-test
3. Rondas de prueba
4. Rondas experimentales
5. Cuestionario
6. Pago

Las repasaremos en detalle un poco más adelante.

Reglas básicas

Para que el experimento funcione necesitamos llevarlo a cabo de acuerdo a unas pocas, pero estrictas, reglas:

- A partir de ahora y hasta el final del experimento, por favor no hables (¡no tardaremos demasiado!) y apaga tu teléfono móvil.
- Si tienes alguna(s) pregunta(s) sobre el experimento o alguna de sus partes, simplemente levanta tu mano y el experimentador se acercará a tu escritorio a responderla(s).
- Por favor no uses el ordenador hasta que se te lo indique.

Las 6 secciones

1 Instrucciones

El experimentador leerá las instrucciones en voz alta. Si necesitas alguna aclaración, éste es el momento para requerirla. Simplemente levanta tu mano y el experimentador responderá a tus preguntas en forma privada. Por favor, no te quedes con ninguna duda sobre el experimento. Es importante que lo entiendas con todo detalle. Formúlanos toda pregunta que te surja en cualquier momento y que no esté claramente desarrollada en este texto.

2 Mini-test

Es para asegurarnos de que entendiste correctamente las instrucciones.

3 Rondas de prueba

El experimento está organizado en una serie de “rondas”. En cada ronda interactuarás –mediante el ordenador únicamente– con otros participantes y tomarás decisiones que afectarán el montante que obtendrás al final de la sesión.

Como calentamiento, primero jugarás 2 rondas de prueba. Estas rondas de prueba son idénticas a las rondas experimentales en todos los aspectos, excepto uno: el efecto sobre el dinero que obtendrás. Las rondas de prueba NO afectarán el montante que recibirás al final del experimento. Pero te permiten observar cómo funcionan las cosas y familiarizarte con las pantallas, tablas, botones y comandos del experimento. Las rondas de prueba también te permiten cometer algunos errores sin por ello perder dinero.

4 Las rondas experimentales

Ésta es la parte importante. Lo que hagas durante estas rondas determinará el montante total que obtendrás.

Las siguientes “Preguntas frecuentes” te instruirán sobre la mecánica básica de las rondas.

4.1. ¿De qué se trata todo ésto?

Comencemos por decir que el experimento consistirá en una serie de rondas. En cada una de ellas el ordenador te agrupará con otros 3 participantes, aunque tú nunca sabrás las identidades de dichas personas. Es decir, el experimento es anónimo: tú sabes que compartes grupo con otras 3 personas, pero no sabrás quiénes son dichas 3 personas ni ellas sabrán quién eres tú. El ordenador elegirá aleatoriamente a tus compañeros, todos los cuales son a priori igualmente probables de formar parte de tu grupo. Los otros 3 participantes serán asignados así: A partir de las 24 personas en el laboratorio, el ordenador formará 3 “megagrupos”, cada uno compuesto de 8 personas elegidas aleatoriamente por el ordenador (es decir, cada una de las 24 personas en el laboratorio tiene la misma probabilidad de ser asignado a un megagrupo determinado). Tú seras asignado a algunos de los 3 megagrupos, y pertenecerás al mismo durante todo el experimento. En cada ronda, el ordenador repartirá aleatoriamente a los 8 integrantes de cada megagrupo en 2 grupos de 4 personas cada uno. Es decir, cada una de las otras 7 personas de tu megagrupo son a priori igualmente probables de formar parte de tu grupo de 4.

Nota: La composición de tu grupo en una ronda dada no tiene ningún impacto sobre la composición de tu grupo en el futuro: cada posible composición de tu grupo es igualmente probable en cada ronda.

Las rondas experimentales están divididas en 2 grupos: un primer grupo de 12 rondas en el que se aplicarán las reglas especificadas en estas instrucciones, y un segundo grupo de 12 rondas en el que se aplicarán otras reglas –aunque similares a éstas– que te serán indicadas al finalizar las primeras 12 rondas.

4.2. ¿Qué tengo que hacer?

En cada ronda tienes que decidir cómo utilizar tus recursos. Para ello todos recibiréis al comienzo de cada ronda recursos personales iguales a 100 "pesetas".

Hay dos posibles usos para los recursos: la actividad Y y la actividad Z. Puedes elegir la una o la otra haciendo click sobre el botón correspondiente en la pantalla "Tu decisión" (figura 1).

Nota importante: Si eliges la actividad Y, entonces todos tus recursos (las 100 pesetas) son direccionados a la actividad Y. Si eliges la actividad Z, entonces todos tus recursos (las 100 pesetas) son dedicados a la actividad Z.

[Figura 1: Pantalla "Tu decisión"]

4.3. ¿Cómo se determina el resultado que obtengo en cada ronda?

El resultado de la ronda depende de tu decisión respecto al uso de tus recursos (aplicarlos a la actividad Y o a la Z) y de las respectivas decisiones de las otras personas de tu grupo. Nota que al momento de tomar tu decisión NO SABRÁS las decisiones tomadas por las otras personas de tu grupo.

4.4. ¿Pero exactamente cómo se determina mi resultado de la ronda?

Tu resultado total (R) es la suma de dos componentes: (1) el componente "A", que (puede) ser diferente para diferentes personas en el grupo; y (2) el componente

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