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KINDNESS, CONFUSION, OR…. AMBIGUITY?

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Kindness, Confusion, or…. Ambiguity?

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Abstract
Kindness or confusion are the main explanations put forward to justify positive contributions in VCM games. Eichberger and Kelsey (2002) provide an alternative rationale based on uncertainty aversion. Uncertainty increases the perceived marginal benefit of own contributions, which in equilibrium exceed the Nash level. We present an experiment which tests this hypothesis, based on two treatments. In the first, human players know that the virtual player will choose out of two alternative contributions with equal probabilities. In the second, the probabilities of the two values are unknown. In order to control for altruism, human players play with virtual agents. Contributions in the first treatment are significantly lower than in the second provided the parameter set allows the players to contribute either the Nash or the Pareto optimum.

Keywords: VCM, free-riding, ambiguity, virtual agent.
JEL codes: C91, D81, H41

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Introduction

In a standard Voluntary Contribution Mechanism (VCM) game, players are endowed with a number of tokens to be allocated between a private and a public good. Each token allocated to the private good yields a constant return for the investor, whereas each token allocated to the public good yields a return which depends on the sum of players' contributions. Typically, with a linear payoff function to the public good, the return to the investor is below the return of the private good, and in the Nash equilibrium the player contributes zero to the public good. Hence, rational individuals will free ride and voluntary provision is impossible.

However, experimental findings on the voluntary provision of public goods contradict this prediction. The main results show that: (i) in one-shot trials and in the initial stages of finitely repeated games, subjects generally contribute halfway (40%-60% of the initial endowment) between the Pareto-efficient level (full cooperation) and the free riding level; (ii) contributions decline with repetition; (iii) face to face communication fosters contributions (Davis and Holt, 1993).

Two main competing explanations for positive contributions have been put forward: either altruism or reciprocating behaviour (Ledyard, 1995), or noise stemming from decision errors or confusion about the rules of the game (Andreoni, 1995).

An alternative explanation for contributions exceeding the Nash level has been proposed by Eichberger and Kelsey (2002), based on the concept of ambiguity aversion (Ellsberg, 1961). Ambiguity arises when a decision-maker finds it difficult or impossible to assign a subjective probability to an event. Ellsberg defined ambiguity as "a quality depending on the type, amount, reliability and "unanimity" of information, and giving rise to one's degree of "confidence" in an estimate of relative likelihoods"(p. 657). Experiments have shown that ambiguity may have significant effects both in individual decision-making settings and in markets (Camerer and Weber, 1992).

Contributors to public goods may perceive the contributions of others as ambiguous. With a concave payoff function from the public good, uncertainty reduces the perceived contributions of others, and thus increases the anticipated marginal benefit of own contributions. Eichberger and Kelsey show that if players are averse to ambiguity, then an increase in uncertainty brings about higher contributions. The hypothesis that voluntary contributions to public goods are positively related to uncertainty accords intuitively with the stylised experimental facts listed above. In fact, ambiguity is certainly greater in one shot games, and decreases with repetition and experience. The effect of face to face communication, however, may be ascribed either to the reduction of uncertainty, or to altruistic or fairness considerations, or both.

Although the predictions of the model have intuitive appeal, to our knowledge there is no research on the impact of uncertainty on contributions to public goods.

This paper presents an economic experiment that tests Eichberger and Kelsey's hypothesis. Since other regarding behaviour is the main competing explanation, an experiment intending to test the empirical relevance of uncertainty must rule it out from subjects' motivations. In order to achieve this, we run experiments in which a human player interacts with a virtual agent. Further, in order to identify the effect of ambiguous probabilities, the experiment contrasts behaviour in a VCM game in which the probability of alternative values of other contributions are known with behaviour when those probabilities are unknown.

The paper is structured as follows: section 1 presents the literature, section 2 discusses the experiment's design, section 3 analyses the experimental results. Section 4 concludes.

1. Background

VCM games with interior Nash equilibria

The Nash equilibrium in the standard VCM with linear payoffs entails zero individual contribution to the public good. The majority of experiments on VCM games adopts such a boundary equilibrium setting. In this case, any departure from the Nash prediction corresponds to positive allocations to the public good. At the same time, the socially optimal allocation is to allocate all endowment to the public good. The stylized facts of VCM games described in the introduction are commonly explained in terms of altruism, reciprocity and signalling. However, some scholars (Andreoni, 1995; Sefton and Steinberg, 1996; Keser, 1996; Chan *et al.*, 1996) pointed to an alternative explanation that can be ascribed to confusion on the part of participants. In other words, positive contributions to the public good might merely be the path of behavioural errors as the system converges towards the zero-allocation equilibrium. This stream of research suggests that it would be more realistic to consider that both the public and private goods are subject to diminishing marginal values. This feature requires the payoff function to be nonlinear in either private or public good consumption. Laury and Holt (2008) thoroughly discuss design issues and experimental results linked to interior Nash structure in public goods experiments. There are two common ways of introducing non-linearities into VCM games: both solutions lead to an interior Nash equilibrium but the nature of those equilibria may differ accordingly.

The first setup requires a non-linear value of private consumption and it yields a unique Nash equilibrium in dominant strategies. Keser (1996) shows that moving the equilibrium away from the boundary results in more dominant-strategy behaviour in the final rounds of the sessions. Van Dijk *et al.* (2002) confirm Keser's results. However, moving the equilibrium away from the boundary is not sufficient to induce Nash behaviour in VCM experiments, given that systematic over-allocations to the public good persist. The second setup entails a diminishing marginal value of the public good, whereas the marginal value of the private good stays constant. If this is the case, for conveniently specified parameters, there is a unique aggregate Nash equilibrium in the interior of the decision space. Nevertheless, there are multiple individual equilibria according to others' contributions. Isaac and Walker (1998) demonstrated that the position of the aggregate Nash equilibrium, relative to the group aggregate endowment, affected contributions to the public good. Other works explored boundary effects by holding the Nash equilibrium constant and moving the lower boundary closer to it (Andreoni, 1993; Chan *et al.*, 1997). Finally, Laury *et al.* (1997) showed that the way in which subjects perceive the trade-off between allocations to private and public goods depends on how the earnings structure is presented.

Public goods and ambiguity

In what follows, we briefly summarise the model of public goods provision under ambiguity by Eichberger and Kelsey (2002) (EK henceforth).[1]

Assume a standard VCM game in which each of n players decides how much of a given endowment to invest in a private good and in a public good. The model is deterministic except for the fact that individuals are uncertain about the contributions of others. This uncertainty entails that they are unable to assign precise probabilities to the distribution of other players' contributions. Players are assumed to have Choquet Expected Utility (CEU henceforth) preferences (Schmeidler, 1989). In this functional, players' beliefs are modelled by non-additive probabilities called capacities. Under ambiguity aversion, CEU implies that individuals overweigh the worse outcomes of any given option.

Assume now that there are decreasing returns to scale to the investment in the public good. In such a case, public goods provision can be likened to a game with positive aggregate externalities and strategic substitutes, i.e. a player's utility is an increasing function of the total contribution to the public goods, and the marginal benefit of increasing one's action given the other players' strategy profile is strictly decreasing. When contributions of others increase, the supply of the public good increases. This reduces the marginal utility of the public good and hence of own contributions.

In such a game, ambiguity will increase voluntary contributions to the public goods compared to the no ambiguity case. In fact, with positive externalities increasing ambiguity increases the weight placed on lower strategies of opponents. With strategic substitutes, ambiguity increases the marginal benefits of own contributions. In short, ambiguity reduces the perceived contributions of others and

[1] The model focuses on symmetric games with symmetric equilibria.

thus increases the anticipated marginal benefit of own contributions.[2] Voluntary provision of the public good becomes more likely the greater the concavity of the payoff function.

Eichberger *et al.* (2008) present an experimental test designed to study the effect of varying strategic uncertainty in games with either strategic complements or substitutes. However, the test does not consider the case of positive externalities and strategic substitutes, i.e. a situation alike public goods provision. [3] The next section presents an experiment which investigates the impact of ambiguity in a game with positive externalities and strategic substitutes.

2 - The experiment

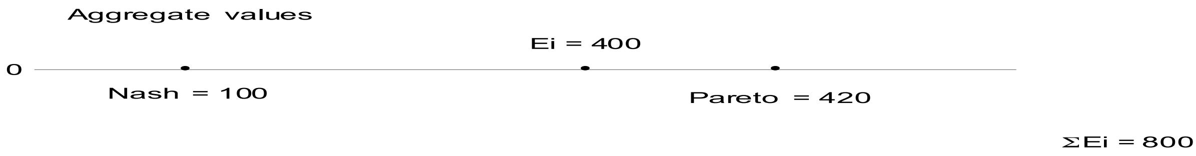
2.1. The game

The experiment is organised as a standard VCM game run for ten periods with groups made up of two players. The payoff function follows that of another VCM experiment with interior Nash equilibrium (Laury *et al.*, 1997).

In each period, subjects receive an initial endowment in tokens equal to 400 tokens which has to be allocated between a private good and a public good. The endowment remains constant throughout the ten periods. Let X define the aggregate contributions to the public good. The marginal benefit from investing in a private good is equal to 1, whereas the marginal social benefit from the public good is $G'(X) = 2.3125 - 0.003125X$. Thus, the marginal private benefit is $G'(X)/2 = 1.1563 - 0.001563X$. Equating the marginal private benefit from investing in the public good to 1, the Nash equilibrium requires that the sum of contributions to the public good is equal to 100 tokens, whereas the Pareto optimum corresponds to a sum of contributions equal to 420 tokens. This implies that the space of strategies is the following:

2 Risk aversion, may lead to increasing contributions but it is not a sufficient condition (see Austen-Smith, 1980; Sandier *et al.*, 1987).

[3] The test considers strategic complements and positive externalities (with simple and multiple equilibria), and strategic substitutes and negative externalities.



2.2. Controlling for kindness

In devising a test of the impact of uncertainty on voluntary contributions to public goods, it is crucial to be able to exclude all competing explanations in order to arrive at clear-cut results. It has been argued that when cooperation is observed in public goods games, it is due either to the fact that subjects make mistakes because they do not understand the rules of the game, and thus they are "confused" (Andreoni, 1995), or that they act on the basis of altruism or reciprocation or social ethics such as fairness. Both explanations may account for the decay in private contributions which generally occurs in repeated VCM games: repetition reduces errors, and on the other hand, failure to obtain reciprocal cooperative behaviour in early rounds may convince cooperative subjects to abandon such a strategy. As Andreoni's work itself has proved, disentangling other-regarding behaviour from confusion is no easy matter. Houser and Kurzban (2002) and Ferraro *et al.* (2003) provide a straightforward design meant to exclude social motives from potential explanations of behaviour. Individual subjects are placed into groups in which the other players are computers.

We replicate the use of virtual players to control for socially oriented behaviour. In our experiment, groups are made up by two players: one human subject (i) and one virtual agent (j). Unlike Houser and Kurzban (2002), however, our virtual player does not choose randomly from an interval of values, but rather from two different values, X_1^j and X_2^j.[4] The random process whereby one of the two values is chosen will be explained in the next section. The two values changed from one period

[4] This accords with EK's model in which the opponent strategy set is discrete.

to the next, so that the optimal Nash-compatible choice for the human player varied across periods. Further, the virtual player possible choices were built so to create two alternative choice sets which were randomly matched with human subjects participating in any session. In the first choice set X_1^j and X_2^j were below or equal to 100. This implies that both the aggregate Nash (100 tokens) and the Pareto (420 tokens) optima were achievable. In the second choice set both X_1^j and X_2^j were greater than 100, so that the Nash equilibrium was no longer achievable, and the human player optimal non-cooperative choice was to contribute zero to the public good. Table 1 summarises the design.

[Insert Table 1 about here]

The virtual player's contributions were independent of the action of the human player. In the tutorial that preceded the game, participants were told several times that the computer's contributions would be unaffected by the subject's own contributions. Subjects were further given an instance of this during the dry rounds, and were reminded of it during the game. This information was obviously provided in order to rule out the belief that the virtual player acted strategically, which may have given rise to expectations of reciprocity.

2.3.Making ambiguity operational

An ambiguity averse decision maker prefers to bet on an event whose probability is known rather than on an equivalent event with vague probabilities. The experiment by Ellsberg (1961) is the classical example of ambiguity aversion. Confronted with an urn containing 100 red and black balls in a ratio totally unknown to the decision maker (the ambiguous urn), and an urn with 50 red and 50 black balls (the risky urn), the decision maker strictly prefers to bet on the latter. This pattern of choice implies that under ambiguity, probabilities for the two complementary events, red and black, do not add up to one, and thus an additive probability distribution cannot be inferred from choice.

Why does ambiguity aversion arise? Ellsberg defines it “a quality depending on the type, amount, reliability and “unanimity” of information, and giving rise to one’s degree of “confidence” in an estimate of relative likelihoods“(p. 657). Frisch and Baron (1988) ascribe ambiguity aversion to the fact that the decision maker lacks the knowledge about some aspects of the stochastic structure of a problem that are unknown but could be known.

In order to test for the impact of ambiguity in a laboratory experiment, it is crucial to decide how to make it operational. Experiments in psychology and economics have created ambiguity either through a chance process or as natural event uncertainty. Experiments based on chance processes either replicate Ellsberg’s experiment, or compare events in which the probability is known with others in which only the probability of the probability (i.e. the second order distribution) is known (Gardenfors and Sahlin, 1982; Halevy, 2007)). Natural event uncertainty consists in tying the outcome of a lottery to the occurrence of a natural event whose probability cannot be objectively assessed, and which may be more or less familiar to the decision-maker (e.g., it will rain tomorrow in London, or, it will rain tomorrow in Kuala-Lumpur). This way of solving uncertainty in experiments (Heath and Tversky, 1991; Fox and Tversky, 1995; Keppe and Weber, 1995; Di Mauro, 2008) has been proposed on the grounds that any random device used to create ambiguity, including Ellsberg’s urn, can be reduced to a second order probability distribution (Hey *et al.*, 2007). If the reduction principle applies, this can be further reduced to a known probability. A different standing is taken by theories (Segal, 1987 among others) which model ambiguity aversion as linked with the violation of the axiom of compound lotteries. Halevy (2007) reports experimental evidence in support of the latter.

In our experiment the preference of more/less uncertainty was made operational through the Ellsberg urn, and was manipulated on a between-subject basis. Two treatments were built which were submitted to two different groups of participants:

Treatment 1 (Risky scenario) **-** human players know that the virtual player will contribute either X_1^j or $X_2^{\,j}$ ($X_1^{\,j}$, $X_2^{\,j} \geq 0$) with equal probabilities. The actual choice of the virtual player is determined through the toss of a coin at the end of every period of the game.

Treatment 2 (Ambiguous scenario) **-** The probabilities of $X_1^{\,j}$ and $X_2^{\,j}$ are unknown. Prior to the choice of the contribution level, the uncertainty they face is described to participants through the Ellsberg urn. More precisely, subjects are told that the virtual agent chooses X_1 if a black ball is drawn from an urn containing 100 black and white balls in unknown proportion. The lottery between X_1 and X_2 is played out at the end of each period of the game in order to determine returns, and subjects are shown the urn at the end of every round in the format shown below.

[Insert figure 1 about here]

In order not to reduce the amount of ambiguity across rounds, the composition of the urn was changed in every period drawing a random number between 0 and 100 to determine the number of black balls (Sarin and Weber, 1993). Subjects were simply told that the composition of the urn would be determined through a random device.

This method of creating ambiguity presents pros and cons. The main advantage is that it is easy to administer and simple for the subjects to understand. However, especially in repeated tasks the decision maker may learn that both events in the ambiguous urn are equi-probable, and thus the vague distribution may boil down to a known distribution. This problem is mitigated by the fact that the second order process is not described explicitly to players. However, if the second order nature of the distribution in the urn is not made clear, there may be a problem of transparency and credibility of the experiment's procedures. Although we are aware of these shortcomings, the choice of the Ellsberg urn vis a vis the "natural event" specification was dictated by a priority we faced in designing the experiment: that of keeping the level of "confusion" about the game as low as possible. Above all, it was crucial to avoid that confusion was higher in the ambiguous scenario with respect to the risky one, since this would have created a perilous confounding. Although we cannot rule out completely the possibility that the Ellsberg urn is perceived as more confusing than the toss of the coin, we believe that this design minimises the effect.

Another way to justify our choice is empirical rather than theoretical in nature. Even if the Ellsberg urn were actually interpreted as a second order probability distribution, the evidence provided by the experimental literature shows that individuals *do* react to second order probabilities (Di Mauro and Maffioletti, 2001; Halevy, 2007).

2.3. Dealing with "confusion"

In order to keep confusion about the game down to a minimum, we provided subjects with a painstaking explanation of the rules of the game through both standard instructions and visual aids. More specifically, the way we dealt with the confusion problem was to dedicate plenty of time to the explanation of the game. Once all participants had sat down in front of their computer terminal, they were provided with written instructions (see appendix) and allowed ten minutes to read them. Next, a pre-game tutorial lasting about 20 minutes was imparted using an overhead projector. This tutorial undertook to explain all the relevant points of the experiment and, in particular, illustrated how to use the two tables shown in the instructions. Participants were actively encouraged to ask questions and to answer questions posed by the monitor concerning the way the experiment worked. Two dry rounds were finally conducted before the actual game began.

Even assuming that we have been successful at teaching subjects how to play, it is likely that confusion decays in the course of the game because of subjects' learning through experience. Most types of repeated experimental games (see for instance market experiments) observe that the deviation of observed values from equilibrium ones decreases through time. We hypothesize that this learning is reduced by the fact that the virtual player choice set is not stationary but changes across periods. In addition, as already stressed in the previous section, the underlying stochastic process used to resolve uncertainty may add to confusion. For this reason, the problem of measuring the decision error is further addressed in the econometric analysis of the experimental data.

2.4. Hypotheses tested

Because human players cannot benefit from contributing in excess of the Nash level, nor can they benefit other players, cooperation in Treatment 1 can only be attributed to confusion. However, as Houser and Kurzban (2002) aptly underline, such attribution implicitly assumes that there is no altruism towards the experimenter, that subjects do not attempt to satisfy the social norm that inhibits greed, and that they have understood and believed that the computer player does not act strategically. Next, assuming that players are no more confused by the Ellsberg's urn than by the toss of a coin, we expect contributions in Treatment 2 to diverge from those of Treatment 1 because of uncertainty. Should contributions under uncertainty exceed those under risk we would take it as evidence in favour of EK's model. Further, we expect this effect to be more marked for those choice sets in which the Nash aggregate optimum can effectively be achieved. Thus, our main hypothesis can be stated as follows:

Hypothesis: Contributions under uncertainty will exceed those under risk because of ambiguity aversion.

2.5. Subject pool

Ninety-four undergraduate students of University of Catania (Italy) took part in the experiment. Subjects were randomly assigned to one of the treatments upon signing up. Each session lasted about 50 minutes, of which 20 of actual game playing and the remaining of instructions, tutorials, etc. Tokens earned throughout the ten periods of the game were converted into euros at the exchange rate of 1 token = 0.10 euros at the end of the experiment. Subjects received €3.00 for participating, in addition to their earnings in the course of the experiment. Average reward for participation was € 9.00.

3. Results

3.1. Descriptive Analysis

This subsection gives a general overview of the experimental results, and provides preliminary evidence in favour of the EK model.

Table 2 shows the minimum, maximum, mean and standard deviation of individual human contributions as a proportion of endowment (400 tokens). All rounds of the game have been averaged. The table shows that the mean contribution in the ambiguity scenario exceeds that in the risky scenario when the Nash aggregate equilibrium can be achieved (NP). No difference is to be found when only the aggregate Pareto optimum can be reached.

[Insert Table 2 about here]

Figures 2 further compare average contributions (across players) for each round in the different cells of the experiment. Again, when the choice set of the virtual player is of the NP type, the ambiguity scenario gives rise to markedly higher contributions (Figure 2A). The difference is significant according to the Wilcoxon matched pair test ($p = 0.005$). On the contrary, when the virtual player choice set is of the P-type (Figure 2B), results are mixed and we cannot reject the hypothesis of equal distributions ($p = 0.575$). A Mann Whitney U-test was further carried out to compare contributions under risk and ambiguity within each period. Under the P-type, the equality of distributions under risk and uncertainty can never be rejected. Under the NP-type, equality is rejected in periods 1,3,7, 8,9,10.

[Insert Figures 2 about here]

The two figures further show that contributions decay across rounds. We calculated non parametric correlations between each subject's contributions to the public good and the time trend, and then we applied a sign test of the null hypothesis that the correlation was zero. The null hypothesis of zero median correlation against that of a median correlation below zero (and thus of significant decay through the game) was rejected only for the risky scenario with NP-type opponent (Binomial($n = 25$, $x >= 19$, $p = 0.5$) = 0.0073).

Two observations emerge:

OBSERVATION 1 - Contributions are significantly higher under ambiguity when the virtual player choice set allows the human player to contribute either the Nash or the Pareto optimum.

OBSERVATION 2 - No significant difference between the risky and the ambiguous scenarios emerges when Nash is not an available option.

Can these observations be reconciled with EK's model, i.e. with the hypothesised effect of ambiguity on contributions? EK show that ambiguity aversion gives rise to higher contributions if there are decreasing returns to scale in the production of the public good. In turn, this entails that there is an interior aggregated Nash optimum. Once the choice set of the virtual player is such that the aggregate Nash is no longer available, *de facto* every marginal increase in individual contributions has a negative private net benefit, so that the player is better off allocating nothing to the public good both in the risky and in the ambiguous scenario. Thus, no difference between risk and uncertainty is expected under the P-type choice set. This accords with the results reported in figures 2. However, a cursory look at figure 2B reveals that contributions under the P-type are well in excess of the full free-riding level. Based on individual mean contributions, the hypothesis that the mean contribution is the full free-riding level of zero is always rejected (in the last round $t = 3.074$, $p = 0.06$ under risk; $t = 3.314$, $p = 0.03$ under ambiguity).

Mean individual contributions in the last round are not significantly different from the Nash aggregate optimum (100 tokens) with the NP choice set ($t = -1.721$, $p = 0.09$ under risk; $t = 1.002$, $p = 0.326$ under ambiguity). Thus, there is likewise an excess contribution with respect to the Nash predictions. Since in this experiment altruism is an unlikely explanation for over-contribution, players may have poorly understood the game, or the experimental instructions may have led players to erroneously use the Nash aggregate as an anchor. Indeed, VCM experiments with interior Nash optima have proved more difficult for subjects to understand and perform with respect to games with boundary equilibria. Thus, we come up with a third observation:

OBSERVATION 3 – The Nash equilibrium poorly predicts contributions to the public good.

This result is in line with other papers (Isaac and Walker, 1998, Laury *et al.*, 1997) which have used concave payoff functions for the public good.

3.2. Panel Analysis

3.2.1 Data Overview and Empirical Strategy

The design of the experiment ensures that each human player can be considered as one independent observation. This feature turns out to be important because it allows us to assume the absence of endogeneity problems.[5] Thus, the dataset can be considered as a panel data of 82 groups in 10 periods and 12 groups in 8 periods for a total of 916 observations.[6]

The non-parametric analysis of the experimental results led to some observations based on the different propensity to contribute to the public good in the two treatments. The main finding is that, when playing in the ambiguous setting, subjects contribute more if both Nash and Pareto outcomes are achievable than when Nash is the only available equilibrium. The aim of this section is to evaluate by means of regression methods whether the results obtained from the session-level analysis are confirmed.

It is important to consider the alternative ways to statistically analyze the data. In the experimental field, the concern on undetected dependency in the error structure in the regression model induces to

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[5] On the issue of endogeneity see Ham *et al.* (2005).

[6] In one of the laboratory sessions (with 12 groups) a crash of the software at the very start forced us to restart the experiment. However, given that we faced a time limit in the availability of the lab, we had to shorten the length of the experiment. Players were informed that the session would last 8 periods.

consider each session of the experiment as a single observation. In this case the standard approach is Wilcoxon/Mann-Whitney on the average section level data.

Instead, a more recent literature applies micro-econometric techniques to the experimental results. This literature (Ham and Kagel, 2005) concludes that there are no reasons to think that experimental data structurally turn out to be different from field data. By contrary, in the laboratory one can neatly control for exogenous factors and decide the sample size. Thus, this literature supports the use of panel data models with experimental data (Ham *et al.*, 2005).

A preliminary discussion of some issues concerning of our empirical strategy is in order before turning to the econometric results. The first issue regards the choice on how to model the time trend, while the second concerns the effects of specific group behaviours. Regarding the first issue there are two possible approaches. The first one is to use a linear function to capture time effects, whereas the second one is to use a dummy for each period.

The second statistical issue is the way in which the "unobserved individual effects" are treated[7]. The most immediate approach is to assume that the unobserved individual effects are not significant for the model purposes. In this case it can be shown that the usual pooled estimator is the most appropriate. The hypothesis of individual effect insignificance is strong but less restrictive than the one which applies if the unobserved variables are correlated with the observed ones. Another way to treat unobserved individual effects is to use a "fixed effects" specification. In this case one supposes that the single unobserved effect is captured by a dummy variable. However, this way of dealing with endogeneity comes at the cost of accentuating the problem of insufficient variation in variable, since the fixed effect estimator does not utilize between-subject variation. Moreover, this approach makes impossible to include observed individual effects that vary across individuals but are constant for each individual. In such situations, the most used alternative is the "random effects" specification.

[7] For a general discussion on Panel model see Wooldridge (2002) and on microeconometric techniques see Cameron and Trivedi (2005).

Like in several other econometric analyses on public good experiments, the dependent variable is given by the individual contributions to the public good in each period of the game (CONTRIBUTIONS). In order to capture the effect of moving from a risky to an ambiguous decision problem, a dummy variable for the ambiguity treatment is adopted (T_A). Another dummy (NP) captures the availability of both the Nash and Pareto equilibria outcomes for the human player. Given the peculiar effect played by the availability of equilibrium strategies, an interaction term which accounts, at the same time, for being in the ambiguous treatment and having access to both Nash and Pareto equilibria is used in the model instead of the two separate dummies for NP and T_A. Table 3 describes the variables used in the analysis.

[Insert Table 3 about here]

Since the dummies NP and T_A*NP are, by construction, positively related, the estimated coefficients could be somehow biased. In other words, the explanatory power of one dummy could be downplayed by the presence of the other. For this reason, two panel data models are presented: a pooled model and a restricted model conditioned on NP being equal to one. By doing so, we can neatly read the effects of both NP and T2*NP avoiding the risk of estimation bias. Covariates for gender and income levels (LOW, MIDDLE, UPPER-MIDDLE) are also added to the model. Finally, we adopt a linear trend to evaluate the time effects in terms of subject's learning.[8]

3.2.2 Models' Estimates and Results

The estimated models can be written as follows:

$$\mathbf{CONTRIBUTIONS}_{ij} = \beta_0 + \beta_1\,\mathbf{T\_A{*}NP}_{ij} + \beta_2\,\mathbf{GENDER}_{ij} + \beta_3\,\mathbf{LOW}_{ij} + \beta_4\,\mathbf{MIDDLE}_{ij} + \\ + \beta_5\,\mathbf{UPPER\text{-}MIDDLE}_{ij} + \beta_6\,\mathbf{TIME}_{ij} + u_{ij} + \varepsilon_i, \qquad [1]$$

[8] The interpretation of the time trend, however, must be considered with caution. In fact, the choice values of the virtual player change from period to period, and therefore the environment of the human player is not static.

where i refers to individuals (i =1,..,94), j refers to period (j = 1,….,10), u and ε are the disturbance terms.

$$\textbf{CONTRIBUTIONS}_{ij} = \beta_0 + \beta_1\,\textbf{T\_A*NP}_{ij} + \beta_2\,\textbf{GENDER}_{ij} + \beta_3\,\textbf{LOW}_{ij} + \beta_4\,\textbf{MIDDLE}_{ij} + \beta_5\,\textbf{UPPER-MIDDLE}_{ij} + \beta_6\,\textbf{TIME}_{ij} + u_{ij} + \varepsilon_i, \text{ conditioned on } \textbf{NP}=1, \quad [2]$$

where i refers to individuals (i =1,..,50), j refers to period (j = 1,….,10), u and ε are the disturbance terms.

In the pooled model [1] we measure the individual contributions to the public good that depend on the interaction between being in the ambiguous treatment and playing with a NP-type virtual player. Also, we included some regressors referring to socio-demographic characteristics. The variable GENDER tries to capture the effect on individual contributions of belonging to the female subset of participants; the variables LOW, MIDDLE and UPPER-MIDDLE control for possible differences in contributions to the public good due to the different income level of individuals. Finally, the variable TIME verifies the presence of a learning effect.

However, we do not specifically account for the effect of the type of virtual players faced by the human players. In the restricted model [2], we look at the subset of observations for which NP=1 in order to have a clearer picture of the effect of ambiguity on contributions when both Nash and Pareto equilibria are achievable. Given model predictions, NP is expected to positively affect the contribution levels. The amount of tokens allocated to the public good should be higher when also Nash is achievable compared to the case in which Pareto is the only attainable equilibrium. In the latter case, a rational agent should contribute zero to the public good. If the predictions of EK are correct, the sign of the coefficient of the interaction term should be positive given that both effects captured by T_A*NP positively influence the individual contribution levels. In addition, the coefficient obtained from the conditioned model [2] should be higher than the pooled model [1]. Finally in model [2] we also include some socio-demographic regressors.

We estimated models [1] and [2] with panel data random effects and fixed effects.[9] Table 4 shows the results of the estimated models with random effects only, given that the Hausman test shows that the random effect is to be preferred.

The pooled model [1] reports an average individual contribution of 133 tokens, given by the constant. The time trend turns out to be significant but with a very small coefficient describing a decay in the individual contribution equal to 1% of the endowment. The analysis shows that the interaction term T2*NP is highly significant with a remarkable coefficient reporting an increase in contribution of 12% of endowment when human players are in the ambiguous treatment and play with NP-type virtual players. This result is consistent with our previous considerations on the effects of ambiguity and with the outcomes of non-parametric tests. However, the interaction term T2*NP deserves more attention. The reason is that the pooled model does not neatly control for the different type of virtual player faced by the humans, whereas the non-parametric analysis shows significant differences in contribution levels due to the type of virtual players entering the game. Thus, in order to accurately check for this potential estimation bias of T2*NP coefficient, we introduced the restricted model [2].

Model [2] re-estimated model [1] conditioned on NP=1. As expected, the coefficient of the T2*NP is higher that in model [1] and reports an increase in contributions of 16% of the endowment due to ambiguity. Thus, when controlling for the type of virtual players, ambiguity increases contributions compared to the results of the pooled model [1]. Moreover, the average contribution to the public good (167 tokens) is also higher than in model [1] showing that, when paired with a NP-type virtual agent, human players enhance their contributions. The coefficient of the linear trend turns out to be almost identical in the two models reporting a very small decay in contributions. Finally, the variables concerning the gender and income effects are not significant in both models.

[Insert Table 4 about here]

[9] We also estimated a Tobit random effect (censored at 0 and 400) because the dependent variable assumes values included between 0 and 400. The results of these estimates are qualitatively similar to those reported in table 4.

3.3. Applying the logit equilibrium to the identification of decision errors.

We present an econometric analysis of the data generated by the experiment based on the concept of logit equilibrium (Anderson *et al.*, 2007), which is a specific class of the socalled Quantal Response Equilibrium (QRE) (McKelvey and Palfrey, 1995). The idea behind the development of the QRE is that individuals can deviate from the Nash equilibrium because of decision errors. Thus, this equilibrium concept provides a way to disentangle the effect of decision errors from other influences on contributions, for instance altruism (Anderson *et al.*, 1998).

In accordance with the standard logit model, it is assumed that the probability of contributing k to the public good, p(k), is an exponential function of expected returns.[10] This means that the more costly the error, the less likely it is to occur. Further, contributions lie between zero and the player's endowment W ($0 \leq k \leq W$), and every k has a positive chance of being selected, i.e. $p(k) > 0$, for each k.

$$p(k) = [\exp(\prod^e(k)/\mu)]/\sum_k \exp(\prod^e(k)/\mu) \tag{1}$$

Where $\prod^e(k)$ is the expected payoff from contribution k, and μ is proportional to the standard deviation of the error distribution. As μ tends to infinitive, the density function tends to 1/W: every decision becomes equally likely, and choice is completely random.

Let us now consider the case in which the public good game is quadratic and there are two players (i and j). The following draws from Anderson *et al.* (1998). The expected payoff to player i from contributing X_i is given by:

$$\pi^e(X_i) = W - X_i + (mX - cX^2) \tag{2}$$

Where $X = X_i + X_j$, $m > 1$, and $0 < c < 1$. There is a continuum of Nash equilibria satisfying:

$$X^* = (m - 1)/2c. \tag{3}$$

Let us now complicate the picture by explicitly taking expectations over X_j. The expected payoff can be written as:

[10] We assume risk neutrality, so that utility is linear in the expected payoff.

$$\prod^{e}(X_i) = W - X_i + [mX_i + mE(X_j) - cX_i^2 - cE(X_j)^2 - 2cX_iE(X_j)] \quad (4)$$

that can then be substituted into the logit equation. This yields a density function for X_i:

$$f_i(X_i) = K_i \exp \{[(m - 1)X_i - cX_i^2 - 2cX_iE(X_j)]/\mu\}$$

where additive constants and terms not including X_i cancel out of the expression and are subsumed in the constant K_i. A further consistency condition is needed, which requires that the expected contribution is equal to the mean of the actual distribution. Assuming that, as in our experiment, J denotes the virtual player and that X_j can take only two values, X_j^L or X_j^H ($X_j^L < X_j^H$), with equal probabilities $p = p' = 0.5$,[11] gives:

$$f_i(X_i) = K \exp \{[(m - 1)X_i - cX_i^2 - 2cX_i (pX_j^L + p'X_j^H)]/\mu\} \quad (5)$$

where $X_i = 0,\ldots\ldots,400$.

The QRE was estimated for both the risky and ambiguity treatment. For the latter, it was assumed that the subjective probability of both X_j^L and X_j^L was equal to .5, i.e. that subjects were expected utility maximisers.

The hypothesis under test pertains to errors in the risky scenario as compared to the ambiguous scenario:

Hypothesis – the error μ is no greater under uncertainty than under risk

which entails that ambiguity does not give rise to more errors than the risky frame. If this hypothesis is validated, any difference in the level of contributions under the two treatments cannot be attributed to a higher degree of decision errors stemming from the ambiguity design, but to reaction to uncertainty.

Table 5 shows the maximised log-likelihood and lambda, a precision parameter which is the inverse of the decision error μ, for all the virtual player's choice sets in both treatments. Estimation was conducted using GAMBIT (McKelvey *et al.*, 2007).

[11] This does not necessarily mean that the agent knows the risk with certainty, but simply that he considers both outcomes equally likely and that he is not averse to uncertainty.

[Insert Table 5 about here]

The table shows that for the first ten choice sets, which correspond to the availability of both the Nash and Pareto options, the precision parameter is lower under ambiguity than under risk, which suggests that there is more randomness in choice in the ambiguity treatment with respect to the risky one. Mixed results are observed when the Nash equilibrium is not achievable (rows 11-20). However, QRE does not seem to be a good predictor of the experimental data. In fact, in both cases the estimated lambda values are very small, which means that the estimated distributions are very flat. It should be noted that, in quadratic public goods games, the QREs are truncated normal distributions (Anderson *et al.*, 1998). However, as already pointed out, the flatness of the distribution implies that there is more weight in the tails than in a truncated normal distribution, which makes the lambdas very small.[12]

In the context of our experiment, an advantage of the logit equilibrium could be that noisy decisions and the impact of ambiguity can be combined into a single model. This means that it is possible to jointly estimate a "pessimism" parameter, i.e. the probability weight attached to the worst outcome and the lambda.

For example, instead of assuming that the probability assigned to X_j^L is .5, the chance of the lower contribution can be estimated together with lambda to maximize likelihood. This estimation, however, did not produce significant results, and so it is not reported. The introduction of the extra parameter did not improve the explanatory power of our data by the QRE: the precision parameter remained very small. All in all, this indicated that suboptimal choices prevailed. The fact that the human player choice set was very wide ($0 \le X_i \le 400$) possibly influenced this result.

[12] We thank Ted Turocy for pointing this to us.

4. **Discussion and conclusions**

Using the methodology of experimental economics, this paper has investigated the effects of probability ambiguity on contributions to a public good in a VCM game. The aim of the paper was to test the predictions of the model by Eichberger and Kelsey (2002): aversion to uncertainty generates higher contributions to a public good, provided that there are decreasing returns from the public good. Accordingly, the design adopted had considered a public good game with decreasing returns, which entails an interior Nash equilibrium. In order to exclude that uncertainty as a motivation for higher contributions could be confounded with the effect of other-regarding behaviour, players in the VCM game interacted only with virtual players. Players were randomly assigned to two treatments: either Treatment 1 in which the probability distribution of the virtual player's choices was known, or Treatment 2, in which the probability distribution was unknown and was represented by means of the Ellsberg's urn. Thus, the presence (absence) of probably uncertainty was manipulated between subject.

Results show that there is indeed evidence in favour of the ambiguity hypothesis. Contributions in the "ambiguity" treatment are significantly higher than those in the "risky" one, provided the virtual player's choice set actually allows for the achievement of the Nash equilibrium. We believe that the between subject nature of the test makes the fact that contributions under the ambiguous scenario exceed those under the risky scenario particularly noteworthy. In fact, according to the "Comparative Ignorance Hypothesis" by Fox and Tversky (1995), the difference between risky and uncertain situations becomes salient only when individuals have the opportunity to compare the two, which implies that uncertainty aversion is to be observed mostly in within subject experiments on ambiguity. Evidence in favour of this hypothesis in a market setting is provided for instance by Sarin and Weber (1993). Therefore, we would expect the difference between contributions under risk and ambiguity to be even stronger in a within subject experiment.

We are not aware of similar tests of the effects of uncertainty on contributions to public goods. However, our results complement somehow the experimental study by Eichberger *et al.* (2008)

which investigates the effect of strategic uncertainty on games with either strategic complements or substitutes. The authors show that, in line with the EK model's predictions, subjects choose more secure actions in games in which ambiguity is higher.

Results also show that the Nash equilibrium is not a good predictor of behaviour in the experiment, nor is the so-called logit equilibrium, which allows for decision errors in the calculation of the Nash optimum. Contributions remain quite noisy. Two explanations may be at the root of this finding: first, deviations from Nash predictions are commonly found in public goods games with interior Nash equilibria, since these games are more difficult for players to understand, with respect to more straightforward games with lower-boundary, i.e. full free-riding, optima. This is documented in the meta-analysis by Laury and Holt (2008), according to whom "when the Nash equilibrium falls between the lower boundary and the mid-point of the decision space", as it is the case in our experiment, "average contributions typically exceed the equilibrium level". For instance, subjects may have been erroneously understood that the Nash optimum was a dominant strategy. Second, the decision space of players in terms of tokens was quite large (400), and this may have contributed to the high variability of choices observed.

Some limitations of this study must be acknowledged: in the attempt to keep the structure of the game as simple as possible, a "naïve" form of uncertainty was implemented. For the same reason, each human player confronted only one virtual player. As part of our future research agenda, we plan to address these shortcomings. It would be of interest to replicate the experiment increasing the number of virtual players, in order to approximate the effect of "large societies". Also, a test of the robustness of results using alternative definitions of ambiguity is needed.

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Table 1 – Summary of experimental design

	Treatment 1 Risky scenario	**Treatment 2** Ambiguous scenario
Virtual agent choice set 1 (NP) Both Nash and Pareto achievable X_1 , $X_2 \leq 100$	25 subjs.	25
Virtual agent choice set 1 (P) Nash not achievable	22	22

Table 2 – Individual contribution to the public good as a proportion of endowment

		Min	**Max**	**Mean**	**St.dev**
NP	**risk**	.14	.26	.21	.04
	ambiguity	.31	.39	.35	.02
P	**risk**	.14	.35	.24	.08
	ambiguity	.19	.29	.24	.04

Table 3 – Definition of variables

Dependent variable	
CONTRIBUTIONS	Contribution to the public good given by individual *i* in period *j*
Explanatory variables	
CONSTANT	Constant
NP	Dummy variable for the availability of both Nash and Pareto outcomes to players
T_A	Dummy variable for treatment (ambiguous treatment = 1)
T_A*NP	Interaction term for the ambiguous treatment and the availability of both Nash and Pareto outcomes
GENDER	Dummy variable for gender (Female = 1)
LOW	Dummy variable for low income players (Low = 1 if Income < 20000)
MIDDLE	Dummy variable for middle income players (Middle = 1 if 20000 ≤ Income < 40000)
UPPER-MIDDLE	Dummy for upper-middle income players (Upper-Middle = 1 if 40000 ≤ Income < 75000)
TIME	Linear time trend

Table 4 – Results of panel data models

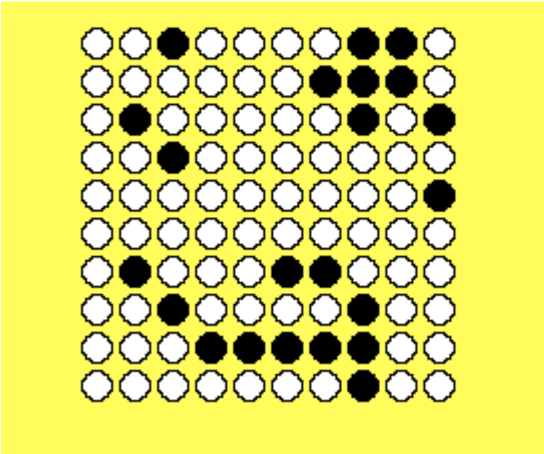
Variable	MODEL [1]	MODEL [2] NP=1
	CONTRIBUTIONS	CONTRIBUTIONS
CONSTANT	132.706*** (40.342)	161.954*** (55.711)
T2*NP	49.299*** (18.706)	62.846 *** (22.382)
GENDER	17.480 (16.291)	4.546 (21.907)
LOW	-29.178 (41.280)	-66.554 (56.377)
MIDDLE	-27.988 (41.135)	-79.760 (55.803)
UPPER-MIDDLE	-23.284 (43.160)	-51.607 (59.817)
TIME	-4.162*** (0.953)	-2.954** (1.345)
Observations	*916*	*492*
Number of groups	*94*	*50*
R-squared	*0.06*	*0.09*
Hausman	*0.41 (0.520)*	*0.37 (0.545)*

Standard errors in parentheses
** significant at 5%; *** significant at 1%

Table 5 – Estimates of QRE.

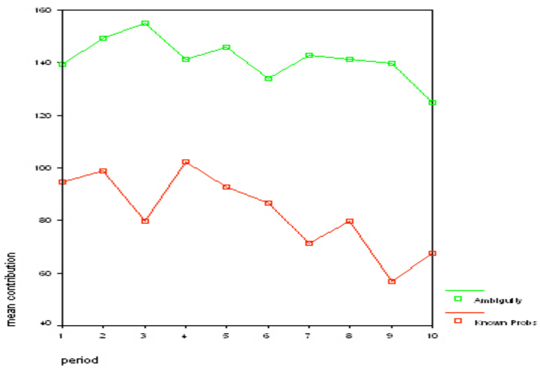
XjL	XjH	Log-likelihood Risk Treatment 1	Log-likelihood Ambiguity Treatment 2	Lambda Risk	Lambda Ambiguity
20	30	139.940479	146.794637	0.067954	0.025361
40	60	143.021193	148.445552	0.037691	0.013151
22	28	141.632697	149.356642	0.105511	0.008707
21	29	104.049105	141.760714	0.044812	0.02043
20	80	143.940478	149.02103	0.03804	0.00977
20	80	141.867206	97.557862	0.004519	0.035653
30	70	132.793491	149.040491	0.063068	0.009642
60	100	140.688386	149.534718	0.038938	0.004884
70	90	140.290188	122.759979	0.049479	0.019707
75	85	479.308452	119.461838	0.059212	0.033252
101	199	132.152242	126.778944	0.025445	0.018473
200	300	125.787185	118.144777	0.01433	0.017564
130	370	121.928165	117.215911	0.0129	0.019153
246	254	128.796042	117.81671	0.009322	0.018122
102	198	129.263912	120.778797	0.012068	0.019091
341	399	113.509422	119.515418	0.025675	0.01751
120	180	128.338257	122.573678	0.014539	0.029222
150	350	121.543724	124.12913	0.021255	0.016986
350	390	115.601373	75.274693	0.022599	0.019026
340	400	113.838241	68.508344	0.025172	0.036087

Figure 1 - The visualization of the Ellsberg urn at the end of a typical round.



Figures 2 - Mean individual contribution by period

2A) Nash and Pareto achievable



2B) Only Pareto achievable