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The Implications of Risk and Uncertainty Aversion in Public Goods Games

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Abstract

In this paper we examine how individuals behave in situations of risk and uncertainty in public and private goods context. We find that subjects are willing to pay a much higher amount to find out information relating to the probabilities of providing the private good than information relating to the public good even if this information has greater consequences for the individual in he public goods context. We find strong support for the free-rider hypothesis and extend it to cases when risk and uncertainty are present. We find that subjects treat risks and uncertainties associated with the provision of private good and public good differently.

JEL classification: C91, Q00, H41

Keywords: Experimental Economics, Public Goods, Risk Aversion, Uncertainty Aversion, Decision Making

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1. Introduction

Due to its importance and implications, decision making has been studied by researchers from a wide range of fields including economics, psychology, political, and environmental science. Particular effort has also been devoted to studying how people perceive, quantify, process and evaluate the probabilities of certain events. In the experimental economic work on risky decision making, probabilities are typically provided or assumed to be known with precision. However, this contrasts with experience in the real world which is more commonly characterized by vagueness or ambiguity concerning probabilities. Probabilities relating to environmental events such as climate change, rainfall, temperature, changes in the ecosystem or the consequences of pollution are a prime example where probabilities are not known with certainty. In the area of climate change, for example, a great deal of uncertainty exists regarding expected global mean temperature changes, sea level rise, melting of glaciers, increase of extreme weather events, costs of mitigation and adaptation, and availability of future technology. How to translate global climate change to local impacts is also uncertain. Policy makers often use models with various scenarios which may occur with different probabilities. Uncertainty regarding the probabilities of these events is sometimes used as a reason to delay policy implementation. A key question in the current research is how decision makers use information when they face risks (known probabilities) and uncertainty (unknown probabilities) and in what way does better knowledge about probabilities alter decisions. We investigate decision makers' preference for known or unknown probabilities when they face private and public goods scenarios. Research question also include determining relationships between risk-attitudes, willingness to pay for information on probabilities associated to returns in a private and public good context, and decision makers' contributions to the public good.

Distinguishing between known and unknown objective probabilities dates back to Knight (1921), with his risk versus uncertainty dichotomy. Knight suggested using the term 'uncertainty' when objective probabilities are unknown and the term 'risk' when the objective probabilities are known. Though Knight's distinction between risk and uncertainty is plausible, several economists have been skeptical of whether the distinction has any behavioral significance. Theorists following the path of subjective expected utility theory (SEU) bypass this issue by assuming that the payoffs for a game are already measured as utilities. In the SEU theory the distinction between known and unknown objective probability is pointless because subjective probabilities are known to decision makers and are inferable from choices. Therefore, whether the subject knows the 'true' objective probabilities is not relevant. Individuals behave *as if* they were maximizing the expected value of some utility function over outcomes, with respect to some probabilities. According to this reasoning, individuals' attitude towards risk and uncertainty should be equivalent, provided the expected (subjective) probabilities of outcomes under uncertainty coincide with the known probabilities of those same outcomes under risk.

Despite the appeal of the SEU theory, most of the empirical evidence suggests that people do make distinction between known and unknown probabilities. The questions to what extent do risk aversion and uncertainty aversion exist, how they depend on different factors, and how they influence decisions is ultimately an empirical issue. Laboratory experiments can provide a control of probabilities and payoffs and, therefore, provide a natural ground for testing the difference that known and unknown probabilities make in the decisions.

Given that the majority of environmental problem can be characterised as either a public good or a common pool resource game, studying how people make decisions when probabilities are known or unknown can contribute to understanding decision-making in the field of environment. Risk and uncertainty, and hence the distinction between known and unknown probabilities have not yet been extensively studied in a public goods experimental context.

In this paper we use experiments designed to capture the difference in the behaviour of subjects under risk and uncertainty using the standard public goods game framework. The risk behaviour of the subjects is captured in two ways: first, subjects participate individually in a lottery game where they face known probabilities. Second, they participate in a public goods game where they face risk or uncertainty. In the latter case subjects are given the opportunity to learn the probability. In this sense the choice to learn the information inherent in the probability of provision of the private/public good is endogenous to the participants.

In Section 2 we review the relevant literature, in Section 3 we describe the experimental procedures and the details of the treatment setup, in Section 4 we provide details of the results, and in Section 5 we conclude and suggest some possible implication of our research findings.

2. Literature Review

Risk has been a fundamental element of both theoretical and empirical research in decision making. Research has shown that people tend to have different risk preferences[1] when facing gains or losses (Kahneman and Tversky, 1979; Allison and Messick, 1985; Andreoni, 1995), when probabilities are high or low (Kahneman and Tversky, 1979; Cohen et al., 1987; Tversky and Kahneman, 1992)[2], when the stake is high or low (Kachelmeier and Shehata, 1992) when buying or selling (Kachelmeier and Shehata, 1992) and when probabilities are in the context of social and nonsocial domains (Loewenstein et al., 1989). Though risk aversion has proven to provide valuable insights into decision making in financial investment, insurance and technological investment decisions, it has limited applicability to several real life scenarios, such as decisions regarding climate change scenarios that are better characterized by "vagueness" or "ambiguity" concerning probabilities.

Ellsberg (1961) put empirical content to Knight's idea and found that, when confronted with the choice to bet on urn I containing 50 red and 50 black balls in known proportions (the risky urn) or to bet on urn II with 100 red and black balls in unknown proportions (the uncertain or ambiguous

[1] The most common description for risk preferences in the literature is risk neutral, risk loving and risk averse depending on the decision maker's preference over a lottery and its expected value.

[2] One of the main results of several laboratory experiments (Kahneman and Tversky, 1979; Cohen et al., 1987; Tversky and Kahneman, 1992) is the interesting pattern of risk attitudes: risk aversion for gains and risk loving for losses at high probability, and risk aversion for losses and risk loving for gains at low probability.

urn), the majority of subjects preferred to bet on the former, an attitude termed since then "uncertainty aversion" or "ambiguity aversion". What is more interesting is that many subjects continued to prefer urn I when its ratio of red and black balls was reduced to 49:51.

Ellsberg's work has generated a great deal of interest in both the realms of the theoretical and empirical research. In the field of theoretical research, Ellsberg (1961) provided an instructive counter example to SEU theory and argued that vagueness about probabilities could lead people to violate the 'Savage axioms' of consistent behavior upon which modern Bayesian decision theory and inference is based. Ellsberg (1961) contended that some of these violations were conscious and deliberate and not careless mistakes that would be retracted after careful reflection.[3] Ellsberg (1961) concluded that Bayesian theory was applicable to decision-making under risk but not to decision-making under uncertainty. Heath and Tversky (1991) convey that Ellsberg "present a serious problem for expected utility theory and other models of risky choice, because (…) most decisions in the real world depend on uncertain events whose probabilities cannot be precisely assessed. (…) [T]he applicability of the standard model of risky choice is severely limited." (p. 6.)

Though Ellsberg did not run formal experiments, his thought experiments were frequently replicated and extended. Becker and Brownson (1964) did the first study in which they presented the subjects with choices of varying ambiguity. The subjects chose between urns containing 100 red and black balls. Drawing a red ball paid $1. The authors operationalized ambiguity as the range of probabilities; the difference in ambiguity is the difference in the ranges while the center

[3] Ellsberg made a test on Savage himself. Savage violated his own axioms. Ellsberg, therefore, concluded, that a reaction consistent with 'Savage axiom' is "by no means a universal reaction; on the contrary, it would be exceptional. (…) Responses do vary. There are those who do not violate the axioms, or say they won't, even in these situations (…); such subjects tend to apply the axioms rather than their own intuition, and when in doubt, to apply some form of the Principle of Insufficient Reason. Some violate the axioms cheerfully, even with gusto (…); others sadly but persistently, having looked into their hearts, found conflicts with the axioms and decided (…) to satisfy their preferences and let the axioms satisfy themselves. Still others (…) tend, intuitively, to violate the axioms but feel guilty about it and go back into further analysis. (…) The important finding is that, after rethinking all their offending decisions in the light of the axioms, a number of people who are not only sophisticated but reasonable decide that they wish to persist in their choices." (Ellsberg, 1961 p. 655-656.)

of probabilities was kept constant. For example, one urn had exactly 50 red balls; another had between 15 and 85 red balls, the third had between 25 and 75 red balls and the last urn had between 40 and 60 red balls. There was also an urn with unknown contents (red ball between 0 and 100). Subjects chose between pairs of urns, differing in the range of red balls, and said how much they would pay to draw from their preferred urn. The authors found that subjects always picked the less ambiguous urn and paid high amounts to avoid ambiguity. Subjects, therefore, were willing to pay to avoid the ambiguous course of action even if that action had an expected value equal to the alternative unambiguous course of action. For example, they paid an average of $.36 to choose from an urn with 50 red balls instead of an ambiguous urn unknown number of red balls even if the expected value of a draw in both cases were $.50. The authors also concluded that as the difference in the ambiguity between two urns decreased, the amount of money subjects were willing to pay to choose the course of action with less ambiguity decreased but the amounts subjects specified were not always proportional to the differences in ranges associated with each pair of urns.

Subsequently, several research (e.g., Slovic and Tversky, 1974; MacCrimmon and Larsson, 1979; Curley and Yates, 1985; Kahn and Sarin, 1988; Curley and Yates, 1989; and Bernasconi and Loomes, 1992) found consistent and strong support for ambiguity aversion in variants of the Ellsberg problems. Hogarth and Kunreuther (1989) demonstrated that even sophisticated subjects who recognized that, from an expected utility theory point of view, ambiguity should not matter indicated a strong aversion to ambiguity.

Risk attitudes are generally considered to be distinguished from attitudes towards uncertainty (Camerer and Weber, 1992; Cohen et al., 1987; Curley et al. 1986; Hogarth and Einhorn, 1990; Fox and Tversky, 1995). Frisch and Baron (1988) conclude that when information regarding the probabilities is missing, people may overweigh the worse possibilities and adjust their choice on the side of caution. Chow and Sarin (2002) examined, in an experimental setting, the role of missing information and its impact on the attractiveness of a bet. The authors distinguished between known, unknown and unknowable uncertainties. The unknown certainty was a case where the subject did not know the probability but believed that some other person might know it, while unknowable uncertainty was where the subject believed that the probabilities were unknown to everyone. The results suggest that the case when the probabilities are known is preferred to the cases when the probability is unknown and unknowable. However, the unknowable case is preferred over the unknown case, i.e. vagueness in probability is more tolerated when others also lack the information about probability and are therefore perceived to be in the same boat.

Sandler et al. (1987) use a probabilistic model in a public goods context. In their model the total quantity of public goods is probabilistic, and individuals bid to increase the amount of the good. They showed that the bid of an individual depends on risk aversion, and that an increase in risk will lead to a decrease in expenditure on the public goods for a risk-averse individual.

Studies, therefore, suggest that the attractiveness of a bet is influenced by several factors over and beyond probabilities and payoffs. Rather than simply extending the existing literature on decision making in the presence of risk and uncertainly, we are interested in finding out how decisions are made in the context of public goods in the presence of risk and uncertainty. There are several examples of this scenario. Decision making in the field of environment for example is abundant with problems that can be characterised as public good games with unknown probabilities. Climate change, biodiversity loss, ecosystem degradation are only some of the global environmental problems that fall into this category.

Rather than confining our research to the simple choice problem, we take the research on uncertainty aversion and risk aversion and apply it in the context of public goods games. It is common wisdom that people behave differently when making decisions about private and public goods. The issue we explore here is whether risk and uncertainty attitudes differ in the two cases as well. Though the public goods game is more complex than a simple lottery choice setup and thus adds some “noise” to our data such as strategic uncertainty, we keep variables affecting the strategic uncertainty constant (e.g., group size, communication) throughout the various treatments. The study helps us understand how individuals behave in real life situations where they face risk or uncertainty and decide on allocating resources to private or public goods.

3. Experimental Design

3.1. Experimental Procedure

Ten sessions were run, each session included 3 treatments, one lottery game, and a questionnaire. Five subjects participated in each of the ten sessions. All subjects participated in all treatments, namely Baseline, Uncertainty in Private Goods and Uncertainty in Public Goods treatments.[4] Each treatment consisted of a sequence of fifteen decision making periods. A group of five participants faced the same investment dilemma and made simultaneous decisions.

The experiment was programmed and conducted with the software z-Tree (Fischbacher, 1999). It was emphasized to the participants that their own decisions were private information appearing on their own screens only and were not to be discussed with other participants. To allow for the consideration of results of the previous periods, participants were asked to record their individual income in every period and any additional information they found relevant to their decisions. At the end of the Uncertainty in Private Goods and Uncertainty in Public Goods treatments subjects were asked to specify their "willingness-to-pay" to learn the information on probability when it was attached to the private or the group account, respectively. A questionnaire was also completed by the participants at the end of the session.

[4] There were some additional treatments run in each session. The results of these treatments are reported in Gangadharan and Nemes (2009). For the purpose of exploring further the difference between risk aversion and uncertainty aversion, we have selected three of the treatments in the current paper. We have controlled for order effects and concluded, that the results in the treatments were independent of each other. Selecting only three of the seven treatments, therefore, had no impact on the accuracy of the results.

3.2. Treatment Description

Baseline Treatment

The baseline treatment is a standard public goods game. At the start of each period, each subject was given the same number of tokens or experimental dollars (E$), ω_i. Subjects had to divide these tokens between contributing to a "private account" (x_i) and a "group account" (g_i). Investment into the private account earned α experimental dollars to the individual only. Contributions to the public account earned $\beta \frac{G}{n}$ experimental dollars to each participant, where $G = \sum_{i=1}^{n} g$. The parameters α and β might be thought of as the "efficiency factors" on the private and the public accounts, respectively. Contributions to the public account, therefore, yielded the same return to all participants, depending on the sum of all contributions but irrespective of the individual's contribution. Therefore, the public account exhibited the public goods' non-excludible and non-rival characteristics. At the end of each period, subjects learnt the aggregate level of contribution to the public good and their return from the private as well as the public account.

In the Baseline treatment, individual i 's payoff is given by:

(1) $$u_i = \alpha x_i + \beta \frac{G}{n}$$

The subjects must maximize this utility function, subject to a budget constraint ($\omega_i = x_i + g_i$), a public goods identity ($G = \sum_{i=1}^{n} g_i$), and a non-negativity constraint ($g_i \geq 0$).

Let's define M as the marginal per capita return (MPCR) – the amount that is generated for each member of the group when one individual contributes a token to the public good. It can also be seen as the marginal rate of substitution of the private good for the public good or as a measure of incentives to contribute to the public good.[5]

(2) $$M = -\frac{\partial u_i / \partial G}{\partial u_i / \partial g_i} = \frac{\beta}{n\alpha}$$

The social dilemma arises if $M < 1$. In this case, a unit investment into the private account provides a subject with more payoff than a unit investment into the public account. On the other hand, taking from every participant a unit of private investment and contributing it to the group account makes each participant better off. Thus, the unique dominant strategy is to free ride (i.e., $g_i = 0$ for $\forall i$) while the socially optimal Pareto efficient solution requires every participant to contribute all their tokens to the group account (i.e., $g_i = \omega_i$ for $\forall i$).

Uncertainty in Private Goods Treatment

In the Uncertainty in Private Goods treatment subjects face uncertainty regarding the probability of return from the private account. Subjects know that the probability of return from the private account is determined by drawing a random number from a uniform distribution but the exact probability is not displayed to the participants. Whether the actual payment will be made once the participants made their investment decisions, is determined by a random number generation process. Therefore, there is uncertainty (i.e., unknown probability) regarding the return from the investment into the private account. To learn the exact probability of return, participants must pay a fee of $f = 20$ from their endowments. When participants choose to do so, the information regarding the probability of return from the private (p_x) account is displayed on the computer screen. This information remains the private information for those participants who paid the fee for the information. Participants who paid 20 experimental dollars for the information remain with $\omega_i - f = 80$ tokens to invest in that period.

[5] The MPCR was introduced by Isaac et al (1984).

This treatment allows us to divide the participants into two distinct groups: those who are willing to pay and, therefore, know the exact value of the probability (facing risk) and those who do not (facing uncertainty).

In order to maintain the payoff equivalence with the Baseline treatment, the parameters have been modified and set $\alpha = 2, \beta = 1.5$. For subjects who act under uncertainty (i.e., do not wish to know the probability) the expected value of marginal per capita ratio remains equivalent to that in the Baseline treatment, i.e. $EM = 0.3$. For subjects who choose to obtain the probability associated with the private account, the expected marginal per capita ratio changes.

At the end of the Uncertainty in Private Goods treatment a questionnaire was filled out by the participants to assess their "willingness-to-pay" for the information regarding the probability of return from the private account. The Uncertainty in Private Goods treatment is employed to learn about the uncertainty attitude of participants in a public goods - private goods contexts when the uncertainties are related to the private good.

Uncertainty in Public Goods Treatment

The Uncertainty in Public Goods treatment mirrors the Uncertainty in Private Goods treatment. In the Uncertainty in Public Goods treatment subjects face an uncertainty regarding the probability of provision of public good. Subjects know that this probability is determined by drawing a random number from a uniform distribution but the exact value of the probability is not displayed to the participants. Therefore, there is uncertainty (i.e., unknown probability) regarding the return from the investment into the public account. To learn the exact probability of return, participants must pay a fee of $f = 20$ from their endowments. When participants choose to do so, the information regarding the probability of return from the public (p_g) account is displayed on the computer screen. This information remains the private information for those participants who paid the fee for the information. Participants who paid 20 experimental dollars for the information remain with $\omega_i - f = 80$ tokens to invest in that period.

Again, at the end of the Uncertainty in Public Goods treatment a questionnaire was filled out by the participants to assess their "willingness-to-pay" for the information regarding the probability of return from the public account. The Uncertainty in Public Goods treatment is employed to learn about the uncertainty attitude of participants in a public goods - private goods contexts when the uncertainties are related to the public good.

Lottery Game

In order to control for risk aversion prior to the computerized experiment, we asked the subjects to participate in a hand run lottery game similar to the procedures described in Holt and Laury (2002). Participants had to indicate their preferences between two lotteries in ten games. In the first case, Option A represents the sure payoff of $7 and Option B represents a lottery where depending on the number drawn from a bingo cage, the payment is in the extremes of $2 (with probability .9) or $12 (with probability .1). Under these conditions, most people will choose Option A. As the probability of the high payoff outcome increases, people tend to cross over to Option B. For example, a risk neutral person would choose Option A in the first four tasks before switching to Option B. The more risk-averse the person, the later he will switch over to Option B. Subjects indicated a preference, Option A or Option B, for each of the ten paired lottery choices with an understanding that one of these choices would be selected at random at the end of the session and played to determine the earnings for the option selected.

Conducting the lottery game was important to reveal the risk preferences of the participants. This is important for us in the analysis in order to separate the effects of attitude of risk aversion from other possible systematic effects on decisions under risk and uncertainty. Conducting the lottery game gives us an additional measure of the risk preference of the subjects which we can then compare with their behavior in the public goods experiments where they face risk and uncertainty and can also help compare our results with other similar studies.

Demographic Questionnaire

Qualitative and quantitative information were also collected from each participant at the end of the session in the form of a questionnaires.

4. Results

In this section we first examine the results from the lottery game and then we analyze the relationship between subjects' risk attitudes and their subsequent decisions to avoid uncertainty. Research question include determining whether risk-seeking or risk-averse individuals are more likely to pay for information on probabilities associated with private and group accounts. We also examine the relationship between risk attitudes, willingness to pay to reveal the probability and individual contributions to the public good.

4.1. Risk Attitudes

The participants' pattern of choices in the lottery game sheet provided an ordinal measure of their risk attitude. Risk aversion is represented by the convexity or concavity of an individual's utility function when faced with the choice between an uncertain payoff and a safe bet. One way to assess the convexity or concavity of this function is to find the bet at which the participant is indifferent between the safe and risky option. In the present context this point is represented by the choice game at which the participant switches from choosing Option A to Option B. Thus, each subject was given a score from 1 to 10 based upon the game at which they switched from choosing the riskless choice (Option A) to the risky choice (Option B). The subjects' scores therefore ranged from 1 (risk averse) to 10 (risk seeking) with a score of 5 for a risk neutral subject.

The majority of subjects were slightly risk averse. Figure 1 shows that 74 percent of the subjects switched from the riskless choice (Option A) to the risky choice (Option B) at the sixth choice game or afterwards and thus are categorized as risk averse. Ten percent of the subjects switched at the fifth choice game, they are marked as risk neutral, while 16% switched before or at the fourth game, hence they are risk lovers.[6]

As explained in the design section, we also collected demographic data from the 50 subjects and we are interested in examining whether these demographic characteristics can explain behavior towards risk in this lottery game. Table 1 presents estimates of risk attitudes from an ordered probit and a binary probit model. In the ordered probit model, risk attitudes are thought to be of three kinds: risk loving, risk neutral and risk averse. The dependent variable hence takes three values 0, 1 and 2. The binary probit risk model separates subjects into two categories: risk lovers (those who switched at or before the fifth choice game) and risk averse (those who switched at or after the sixth choice game). In both the ordered and the binary probit model the independent variables are the demographic variables, like sex of the subject (sex), age (age), how long they have lived in Australia $(auslived)$, whether they have taken courses in economics $(econ)$ etc.

The equations estimated for the risk attitudes are the following: $riskorder$ takes three values and is estimated as an ordered probit and r_lover takes two values and is estimated as a binary probit:

(3) $riskorder_i = \alpha_i + \beta_1 sex_i + \beta_2 age_i + \beta_3 school_i + \beta_4 econ_i + \beta_5 auslived_i + \beta_6 council_i + \varepsilon_i$

(4) $r\_lover_i = \alpha_i + \beta_1 sex_i + \beta_2 age_i + \beta_3 school_i + \beta_4 econ_i + \beta_5 auslived_i + \beta_6 council_i + \varepsilon_i$

As shown in Table 1, it is only whether subjects have taken courses in economics that is significant at 10% significance level; subjects who have taken courses in economics are more likely to be risk lovers.

[6] Subjects often seemed to hesitate around task 5 where there was an expected payoff equivalence between Option A and Option B; choices near the switch point were often crossed out and changed. Two subjects out of the fifty switched between Option A and Option B more than once.

4.2. Uncertainty Aversion

Table 2 and Figure 2 summarize the number of times subjects paid to find out the information about the probabilities they face, in each period. In both treatments subjects start with the same rate (34%). However, in the Uncertainty in Public Goods treatment, this number drops dramatically. In the Uncertainty in Private Goods treatment, there is no particular time trend (the number of times subjects want to know the probability increases slightly and then stays at around 44%). The average number of times the subjects paid to reveal the probability in the Uncertainty in Private Goods treatment is 43 percent while the average number of times the subjects paid to reveal the probability in the Uncertainty in Public Goods treatment is 12 percent across all time periods. The t-statistic for the difference is highly significant with a p-value of 0.000.

After each of these treatments we asked the subjects an open ended question about how much they would be willing to pay out of their initial endowment to reveal the probability regarding the provision of the (private or the public) good. We find that subjects were willing to pay 17 experimental dollars in the Uncertainty in Private Goods treatment and 9 experimental dollars in the Uncertainty in the Public Goods treatment. The difference is also significant (p value= 0.003). This result corroborates previous studies that show that subjects pay substantial premiums to avoid ambiguity – from around 10 to 20 % of expected value of probability (MacCrimmon and Larsson, 1979; Curley and Yates, 1989 and Bernasconi and Loomes, 1992) and up to 72 % (Becker and Brownson, 1964), but extends the results by distinguishing between the probability information relating to the private good and the public good. In the former case the willingness to pay to resolve the uncertainty is higher. This result may be viewed as an extension of the common result of the general public goods games, where typically subjects are willing to pay less to the public account than to the private account. One explanation of this result may be related to the strategic uncertainty that is present in public good games, It may be the case that subjects are not willing to pay to obtain information about probabilities relating to the public account knowing that there still remains a strategic uncertainty with which they can do nothing to reduce or eliminate. It seems that it is the presence of the strategic uncertainty that results in the reduced willingness to pay for the probability information.

Table 3 presents the average contributions proportional to the endowment in the Uncertainty in Private Goods and Uncertainty in Public Goods treatments and compares them to the Baseline treatment. In the Baseline treatment the only uncertainty that subjects face is strategic uncertainty. In the other two treatments, we keep the strategic uncertainty constant and add an additional uncertainty factor regarding the provision of the private or the public good. We find that in the Uncertainty in Private Goods treatment, the contributions are significantly higher than in the baseline treatment (using both t-test and the wilcoxon test). When facing uncertainty on the private good, subjects contribute more towards the public good. This could be due to two reasons. First, subjects having paid for the information regarding probabilities on private account may have discovered that the probabilities are low. Hence, their incentives to contribute to the public account relative to the private account (EM) have increased. Second, subjects may divert away from the uncertain outcome and thus contribute more to the public good. We attempt to separate out these factors in Figures 3 and 4.

As seen in Figure 3 Panel A and Panel B, the contribution levels of the subjects who know the probabilities seem to follow a pattern (marked by diamond shaped symbols) while the contribution levels of the subjects who do not know the probabilities, seems to be random in both treatments (marked by squares). In the Uncertainty in Private Goods treatment (Figure 3 Panel A), the increase in the probability of provision of the private good decreases the contribution levels to the public good. In the Uncertainty in Public Goods treatment (Figure 3 Panel B) the increase in the probability of provision of the public good increases the contribution levels to the public good. Thus, in both treatments subjects react to the change in probabilities and the consequent change in EM.

Figure 4 Panel A and Panel B show, however, that the response to the change in the probabilities associated with the private and the public account are not at all similar. In the Uncertainty in

Private Goods treatment the probabilities seem to be linearly related to the contribution levels. Subjects seem to take these probabilities as a direct guide of how to split their money between the private and the public account. They follow this pattern of gradually increasing their contribution levels despite the fact that the Nash equilibrium (zero contribution) and the Pareto optimum (full contribution) remain unchanged. Note, that it is only when the probability of provision of the private good is very high $(p_x \geq .8)$ that the Pareto optimal outcome coincides with the Nash equilibrium of zero contribution. Subjects seem to realize this and the contribution levels collapse to zero. In the Uncertainty in Public Goods treatment the response to the probabilities seem to be less direct; it is only when the probability of provision of the public good is very high $(p_g \geq .8)$ that the contribution levels start to converge to the Pareto Optimal outcome. Note, that in the Uncertainty in Public Goods treatment for any probability higher than $p_g \geq .4$ the Pareto Optimal contribution level is 100%, while the Nash Equilibrium remains at zero contribution level.

Figure 5 reveals important information: it shows the average proportional contributions of the subjects separated out by the known and unknown probabilities for both treatments. As expected and described previously, the contribution levels of the subjects who know the probabilities adjusts to the information inherent in the probability value and the consequent change in EM. Hence the high volatility of contribution levels across periods. However, from what was thought to be random contribution levels previously in Figure 3 Panel A and Panel B, there seems to emerge a pattern over time. In the Uncertainty in Private Goods treatment, when the probabilities are not know (uncertainty) the contribution levels exhibit a downward sloping trend over time. Despite the downward sloping trend, the contribution levels remain significantly higher than the contribution levels with unknown probabilities in the Uncertainty in Public Goods treatment. In the Uncertainty in Public Goods treatment the contribution levels of those who do not know the probability (uncertainty) remains very low (below 10%) throughout the fifteen periods. There are several examples for both patterns in the literature. For example, Isaac et al. (1984; 1985) and Andreoni (1986) have all replicated, under a variety of conditions, contributions which begin at intermediate levels but then decay in multiple trials. Reasons for the decay include learning and punishing others for not contributing. Learning in our case may mean that subjects learn free-riding behavior from others or that they learn to become less uncertainty averse. Subjects seem to be less uncertainty averse over time when uncertainty is related to the private good and thus prefer the external uncertainty relative to the strategic uncertainty over time.

In both Figure 3 Panel A and Panel B we find that some subjects are willing to pay for the information regarding the probabilities of provision of the private and the public good, however do not seem to take this information into consideration when deciding on contributions. For example, despite the probability of return from the private account being very low (Panel A), some subjects contribute all their endowment towards the private account. In Panel B, even when the probability of provision of the public good is very high, subjects do not contribute to the public good. The interesting thing is not the investment decision, *per se*, but the fact that these subjects were willing to pay for the information about the probabilities despite the fact this information did not seem to play a role in their decisions. One explanation we find for their behavior is that these subjects do not like making decisions in the face of uncertainty. Even if they have decided *ex ante* about their contribution, they are willing to pay a fee to reveal the information just to avoid making decisions in the face of uncertainty.

Next, we examine the relationship between risk attitudes of subjects and their wanting to know the probability associated with provision of the good. Table 4 presents the estimates from an ordered probit equation in which the dependent variable $(want\_to\_know)$ takes the value of 1 when subjects want to know the probability they face and are willing to pay a fee for it. This want to know variable is a function of time $(invperiod)$, sex of the subject (sex), age of the subject (age), lag of total contributions to the public account $(lsumcontrib)$, risk attitudes (two dummies: $risk\_lover$, $risk\_neutral$), lag of the outcome of the good $(lout)$, a binary variable whether the good was provided or not in the previous period[7], and the subject's willingness to pay to reveal the probability related to the private good (wtp_priv) and to the public good (wtp_pub).

(5)
$$want\_to\_know_{ikt} = \alpha_i + \beta_1 invperiod + \beta_2 sex_i + \beta_3 agei + \beta_4 lsumcontrib_{t-1} + \\ + \beta_5 risk\_lover_i + \beta_6 risk\_neutral_i + \beta_7 lout_{t-1} + \beta_8 wtp\_priv_{ik} + \beta_9 wtp\_pub_{ik} + \varepsilon_{it}$$

Where

i = individual (50 individuals)

k = treatment (2 treatments)

t = period number (1-15)

However, the risk variables could be correlated with the unobserved determinants of the want to know variable resulting in a standard endogeneity problem. We control for this by estimating an equation for risk and then using the predicted values from it. We present estimates from both exogenous and endogenous risk specifications. We use the predicted value from the ordered probit (Eq. 3) model (Psuedo R-squared of the ordered probit model: 0.12).

The above equation was estimated separately for both the Uncertainty in Private Goods and Uncertainty in Public Goods treatment. The results show (see Table 4) that in the Uncertainty in the Public Goods treatment subjects have a higher probability of wanting to know the probability of provision, but this tapers off by the end of the treatment. Higher total contributions to the public account in the previous period $(lsumcontrib)$ decrease the probability of subjects wanting to know the probability of provision of the private good in this period, for the Uncertainty in Private Goods treatment, while higher total contributions increase the probability of subjects

[7] The binary variable $lout$ is 1 ("yes return") if the random number generated is less or equal to the probability or return from the corresponding account. Consequently, $lout$ is 0 ("no return") if the random number generated is greater than the probability of return from the corresponding account.

wanting to know the probability of provision of the public good in the Uncertainty in Public Goods treatment. Subjects are using the total contributions of all the members in the previous period as information to resolve the uncertainty. In the Uncertainty in Private Goods treatment, when subjects see that the total contributions were high then they perhaps feel that the public good would give them a higher return and these subjects are, therefore, less willing to spend money on finding out the probability relating to the private good. In the Uncertainty in Public Goods treatment, when subjects see that contributions are high in the previous period, then they perhaps feel that knowing the probability relating to the public good would be a good use of their money (otherwise they would be loosing out) and, therefore, want to invest in finding out the probability they face. In case the subjects make assumptions about the number of participants who know the probabilities by observing the contribution levels, then our results corroborate those in Chow and Sarin (2002) who suggest that the case when the probabilities are unknowable is preferred over the unknown case (unknown to subject but known to someone else), i.e. vagueness in probability is more tolerated when others also lack the information about probability and are therefore perceived to be in the same boat. We should, however, note that for the Uncertainty in Public Goods treatment the number of subjects who want to know the probability is very low (particularly over time, See Table 2) and, therefore, for this treatment, we should be careful in interpreting the results. Subjects who are willing to pay a higher amount to reveal the uncertainty (a hypothetical question) are also more likely to pay the fee in the experiment to know the uncertainty in both the Uncertainty in Private Goods and Uncertainty in Public Goods treatments.

Risk loving subjects (in the Uncertainty in Private Goods treatment) and risk neutral subjects (in both treatments) exhibit a higher probability of wanting to know the probability relating to the provision of the good as compared to the baseline dummy of risk averse subjects. The lottery game that determines the risk attitudes of the subjects captures external risk (known probabilities) but neither attitudes towards uncertainty (unknown probabilities) nor attitudes toward strategic uncertainty. Risk lovers in the lottery game would be willing to take a gamble with know probabilities. How would they behave with unknown probabilities, which is what they face in the two treatments in this study?

It seems that when facing unknown probabilities, subjects who are classified as risk neutral and risk lovers in the lottery game are more interested and willing to pay a fee to know the probability they face. The probability revealing mechanism may be thought of as a gamble itself. The information subjects gain when paying a fee may help them in their decisions, especially if the probabilities are either very high (> .8) or very low (< .2). However, in case the probability is in the mid-range (around .5-.6) then the information gives little guidance to the subjects about how to behave. So when they have to decide to pay a fee for a gamble, the risk lover and the risk neutral subject will more likely do so. Risk averse subjects seem to avoid spending money on this gamble. Another line of reasoning is that requesting unilaterally the probability information may be seen as a "risky" strategy (others may not request it and, therefore, the subject ends up paying for it). Therefore, subjects who paid for the probability run the risk of incurring even greater losses should others not adhere to this strategy.

Further, we are interested in investigating whether subjects with different risk profiles behave differently in terms of contributions to private and public goods. In addition, do subjects who are willing to pay to resolve the uncertainty use this information and contribute towards the public good?

To examine the relationship between willingness to pay and contributions of individual subjects, we conduct multivariate analysis in which we use a random effects generalized least squares (GLS) model. Again the estimation is conducted separately for the two treatments. The dependent variable is the proportional contributions $(contribution)$ made by individuals to the public good.

(6.) $$contribution_{it} = \alpha_i + \beta_1 invperiod + \beta_2 lout_{t-1} + \beta_3 EM + \beta_4 ldeviation_{it-1} + \\ + \beta_5 want\_to\_know_i + \beta_6 risk\_loverhat_i + \beta_7 risk\_neutralhat_i + \varepsilon_{it}$$

The independent variable that we use are the following: time period $(invperiod)$, lag of outcome of the good $(lout)$, the expected marginal per capita ratio (EM), the difference between the individual and group contribution in the previous period ($ldeviation$). Furthermore, we use the predicted value of want to know $(want\_to\_know)$ from the equation above (Eq. 5.) to test whether this variable has a different impact depending on whether it is endogenous or exogenous. We also use the predicted values from the ordered probit risk equation (Eq. 3.) as independent variables $(risk\_loverhat)$ and $(risk\_neutralhat)$ to explain contribution levels.[8]

We find (see Table 5) that subjects who pay to change the probability from uncertainty to risk have a significantly higher probability of contributing to the public good in the Uncertainty in Public Goods treatment (as seen in Figure 5 as well). In the Uncertainty in the Private Goods treatment, the impact is significant only at the marginal level (10% level of significance). Also this impact changes sign depending on whether the specification has an endogenous want to know or not.[9] The negative sign makes intuitive sense as subjects who are willing to pay for more information about the private account, would then be contributing either according to the information they receive or according to some inherent preferences.

Table 5 also shows that $lout$, the variable which measures whether the good was provided in the previous period is positive and significant (Uncertainty in Private Goods) and negative and significant (Uncertainty in Public Goods) in the treatment indicating that a provision of the good in the previous period increases and decreases the contribution to the global good in the current period. Also, $ldeviation$, the difference between the individual and group contribution in the previous period and EM, the expected marginal per capita ratio are very substantial in explaining contributions.

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[8] Ideally it would be good to estimate a system of equations (risk attitudes, want to know and contributions), however we found it difficult to obtain identifying variables to make this estimation meaningful.

[9] The predicted value of want to know has risk accounted for in its specification and therefore in that specification, it leads to a lowering of contributions towards the public good.

The expected marginal per capita ratio (EM) is positive and highly significant in explaining contributions. This result corroborates previous findings and suggests that even when the dominant strategy of Nash equilibrium of zero contribution is maintained, higher marginal incentives, *per se*, significantly increased contribution levels.

The individual level, time specific data that we analyzed above helps us examine the relationship over time between these variables. Next we examine the relationship between average contributions and the average willingness to pay to reveal the probability across the 15 time periods for all 50 subjects. Aggregating across periods might reduce the dramatic impact of the change in the EM variable. Since high and low probabilities (selected randomly from a uniform distribution) even out across all fifteen periods (expected value of .5) the EM may be regarded as constant across all the periods in the two treatments. We use the predicted value from the want to know equation (Eq. 5), also presented in Table 4. (Adjusted r-squared is 0.18 and 0.37 for the Uncertainty in Private Goods and Uncertainty in Public Goods treatments, respectively).

(7.) $$avg\_want\_to\_know_i = \alpha_i + \beta_1 sex_i + \beta_2 age_i + \\ + \beta_3 risk\_loverhat_i + \beta_4 risk\_neutralhat_i + \beta_5 wtp\_priv_{ik} + \beta_6 wtp\_pub_{ik} + \varepsilon_i$$

(8.) $$avg\_contribution_i = \alpha_i + \beta_1 avg\_want\_to\_know\_hat_{ik} + \beta_2 sex_i + \\ + \beta_3 risk\_loverhat_i + \beta_4 risk\_neutralhat_i + \varepsilon_i$$

The results show (see Table 6 and 7) that consistent with the results relating to the individual level, time specific data, the subjects who want to know the probability also contribute significantly more to the public good in the Uncertainty in Public Goods treatment. In the Uncertainty in Private Goods the variable is not significant.

5. Conclusions

In the following we summarize the results and draw some implications of the research results. We use climate change negotiations, as well as research on mitigation and adaptation actions as an example to demonstrate how the above results may be applicable.

It is well established in the experimental literature that people behave differently when they make decisions about private and public goods. We extend the existing literature by exploring whether these behavioural differences persists or amplified when risk and uncertainty is introduced in a private and public goods context and how risk and uncertainty attitudes may relate to the observed behaviour.

Our results show that subjects are willing to pay a much higher amount to find out information relating to the probabilities of providing the private good than information relating to the public good. In both the private and the public good context subjects start with wanting to know the probability at the same rate (34% of the times) but in the public goods context this number drops dramatically very soon while in the private good context this number increases slightly. The average number of times the subjects paid to reveal the probability in the private goods context is much higher (43%) than in the public goods context (12%). This pattern may also be observed in climate change negotiations: after the initial prominence of research on climate change impacts and mitigation (discovering probabilities relating to a public good) there can currently a shift be observed towards more research relating to adaptation (probabilities relating to private good) by countries.

These results are interesting given that the information on probability may have greater consequences on the return in the public good context than it does in a private good context. One explanation may be that even when objective probabilities are known in the public goods context, uncertainty regarding the behaviour of others (ie. strategic uncertainty) exists in the public goods context. The implications of these findings for climate change, for example, may be that without an international collaborative effort (i.e. with strategic uncertainty regarding the actions of other states), individual states' contribution towards scientific effort to gain information regarding the likely impact of climate change may be much less than when international agreements are achieved (i.e. with reduced strategic uncertainty). Reducing the strategic uncertainty thus may increase individual states' willingness to contribute not only towards reducing climate change *per se* but also towards reducing external (environmental) uncertainty by gaining more accurate information on the likely impact. This may have been observed also when early negotiations lead to the Montreal Protocol (reduced strategic uncertainty) and to increased scientific understanding about the likely impact of ozone layer depletion by the collaborating states.

The contribution levels in the public goods context is so low that our findings provide strong support for the free-rider hypothesis and extend these well established findings for cases when risk and uncertainty are present. Decision-makers thus may learn uncertainty aversion from others when information is costly the same way as they learn to free-ride from others. Subjects seem to be less uncertainty averse over time when uncertainty is related to the private good and thus prefer the external uncertainty relative to the strategic uncertainty over time.

Subjects tend to take into consideration outcome of the past period and also use contribution of others as a guide in their behaviour (e.g. deviation from the group contribution and sum of contributions in previous period are highly significant in determining contribution levels). The implications of these findings for climate change negotiations, for example, is that in the presence of risk and uncertainty decision makers increasingly use the behaviour of other participants and the outcomes of previous periods as guidance in their decisions. This indicates that transparency of international negotiations could serve as an important factor in the success of the negotiations. Initial successful collaboration may result in continued success while initial low levels of contributions may also persist. The negotiations leading to ban on ozone layer depleting substances (Montreal Protocol) may be an example of the former while the still ongoing negotiations on climate change (Kyoto protocol) may be an example of the latter.

We also find that decision makers take probabilities relating to return on private goods as a direct guide in making investment decisions. When these probabilities relate to public goods, the response seem to be less direct. It is only when the probability of provision of the public good is greater than 80% that the contribution levels start to converge to the Pareto optimal outcome. In the context of climate change the implications of these findings are that small incremental increase in the likely impacts of climate change may not result in a change in behaviour unless the probability of an impact reaches a certain threshold. An intriguing finding is that some subjects are willing to pay for the information about the probabilities despite the fact this information did not seem to play a role in their decisions.

It seems that when facing unknown probabilities, subjects who are classified as risk neutral and risk lovers in the lottery game are more interested and willing to pay a fee to know the probability they face. The probability revealing mechanism may be thought of as a gamble itself so this may be attractive to risk loving and risk neutral participants while risk averse subjects seem to avoid spending money on this gamble.

Some of these results seem to explain the existing climate change actions (or the lack of them) others may provide support for the role of international agreement in reducing strategic uncertainty and reducing uncertainty.

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Tables

Table 1. Ordered Probit and Binary Probit estimates of Risk

RISK	Ordered Probit RISKORDER		Binary Probit R_LOVER	
Sex	0.098	(0.415)	0.197	(0.433)
Age	-0.037	(0.043)	-0.046	(0.044)
School	0.122	(0.476)	0.255	(0.501)
Econ	-1.078*	(0.613)	-1.202*	(0.637)
Auslived	0.713	(0.506)	0.743	(0.517)
Council	-1.512*	(0.851)	-1.301	(0.903)
cut1	-2.562	(1.377)		
cut2	-2.152	(1.369)		
Cons			2.292	(1.420)

Note: Standard errors are reported in parenthesis.

* significant at the 10 % level

Table 2. The percentage of subjects who wanted to know the probabilities in each period.

Periods	Want to know information about probability	
	Uncertainty in Private Goods %	Uncertainty in Public Goods %
1	34	34
2	38	22
3	44	14
4	54	16
5	42	10
6	44	10
7	44	10
8	44	6
9	34	8
10	44	10
11	44	10
12	46	6
13	44	6
14	42	8
15	42	6

Table 3. Pairwise t-tests and non-parametric Wilcoxon rank-sum tests for the means

Treatment	Baseline
Uncertainty in Private Goods	10.521*** 8.257***
Uncertainty in Public Goods	-9.822*** -9.193***

Note: first number reported in each cell is the t-statistic and the second number reported is the z-statistic from the Wilcoxon rank-sum test.
*** significant at the 1% level

Table 4. Ordered Probit estimates of wanting to know the probabilities with Exogenous and Endogenous Risk parameters

	Ordered Probit							
	Exogenous Risk				**Endogenous Risk**			
WANT_TO_KNOW	**Uncertainty in Private Goods**		**Uncertainty in Public Goods**		**Uncertainty in Private Goods**		**Uncertainty in Public Goods**	
Invperiod	0.533	(0.449)	1.988***	(0.575)	0.505	(0.449)	1.884***	(0.571)
Sex	0.008	(0.112)	-0.267	(0.166)	-0.069	(0.117)	-0.311*	(0.167)
Age	-0.014	(0.011)	-0.016	(0.017)	-0.009	(0.010)	-0.014	(0.017)
Lsumcontrib	-0.002***	(0.000)	0.003**	(0.001)	-0.002***	(0.000)	0.004***	(0.001)
risk_lover	0.198	(0.137)	-0.224	(0.266)				
risk_neutral	0.771***	(0.172)	0.763***	(0.204)				
risk_loverhat					1.025**	(0.425)	-8.005	(5.051)
risk_neutralhat					2.142	(1.686)	21.774**	(10.88)
Lout	0.054	(0.107)	-0.181	(0.157)	0.049	(0.107)	-0.164	(0.156)
wtp_priv	0.038***	(0.003)			0.038***	(0.004)		
wtp_pub			0.041***	(0.006)			0.047***	(0.006)
Cons	-0.235	(0.292)	-1.873***	(0.409)	-0.602*	(0.322)	-3.011***	(0.621)

Note: Standard errors are reported in parenthesis
*** significant at the 1% level
** significant at the 5 % level
* significant at the 10 % level

Table 5. Random Effects GLS estimates of contribution levels with exogenous and endogenous parameter estimates

CONTRIBUTIONS	Random Effects GLS							
	Exogenous Want to Know				Endogenous Want to Know			
	Uncertainty in Private Goods		Uncertainty in Public Goods		Uncertainty in Private Goods		Uncertainty in Public Goods	
Invperiod	0.350***	(0.105)	0.024	(0.052)	0.341***	(0.105)	-0.114*	(0.061)
Lout	0.043*	(0.025)	-0.026**	(0.012)	0.057**	(0.025)	-0.022*	(0.012)
EM	0.313***	(0.029)	0.163***	(0.035)	0.310***	(0.029)	0.174***	(0.036)
Ldeviation	0.003***	(0.000)	0.002***	(0.000)	0.003***	(0.000)	0.002***	(0.000)
want_to_know	0.059*	(0.033)	0.210***	(0.024)				
want_to_know_priv_hat					-0.157*	(0.089)		
want_to_know_pub_hat							0.572***	(0.080)
risk_loverhat	-0.314*	(0.174)	-0.105	(0.111)	-0.237	(0.177)	-0.039	(0.100)
risk_neutralhat	0.029	(0.624)	0.486	(0.401)	0.069	(0.627)	0.112	(0.367)
Cons	0.213***	(0.061)	0.002	(0.037)	0.286***	(0.067)	0.009	(0.034)

Note: Standard errors are reported in parenthesis.
*** significant at the 1% level
** significant at the 5 % level
* significant at the 10 % level

Table 6. OLS estimates of average number of request of probability estimates by subjects

AVG_WANT_TO_KNOW	OLS			
	Uncertainty in Private Goods		Uncertainty in Public Goods	
sex	-0.027	(0.119)	-0.011	(0.049)
age	-0.004	(0.009)	-0.004	(0.004)
risk_loverhat	0.459	(0.457)	-0.184	(0.199)
risk_neutralhat	0.127	(1.706)	1.184	(0.735)
wtp_priv	0.012***	(0.003)		
wtp_pub			0.013***	(0.002)
cons	0.214	(0.291)	0.015	(0.118)

Note: Standard errors are reported in parenthesis.
*** significant at the 1% level
** significant at the 5 % level
* significant at the 10 % level

Table 7. OLS estimates of average contribution levels by subjects throughout the 15 periods (endogenous parameters)

	OLS			
AVG_CONTRIBUTION	**Uncertainty in Private Goods**		**Uncertainty in Public Goods**	
avg_want_to_know_4hat	0.060	(0.212)		
avg_want_to_know_5hat			0.688***	(0.139)
Sex	0.044	(0.091)	0.033	(0.038)
risk_loverhat	-0.395	(0.364)	-0.023	(0.156)
risk_neutralhat	-0.014	(1.272)	0.043	(0.590)
Cons	0.472***	(0.160)	0.008	(0.054)

Note: Standard errors are reported in parenthesis.
*** significant at the 1% level
** significant at the 5 % level
* significant at the 10 % level

Figures

Figure 1. Panel A: Risk Attitude of Subjects

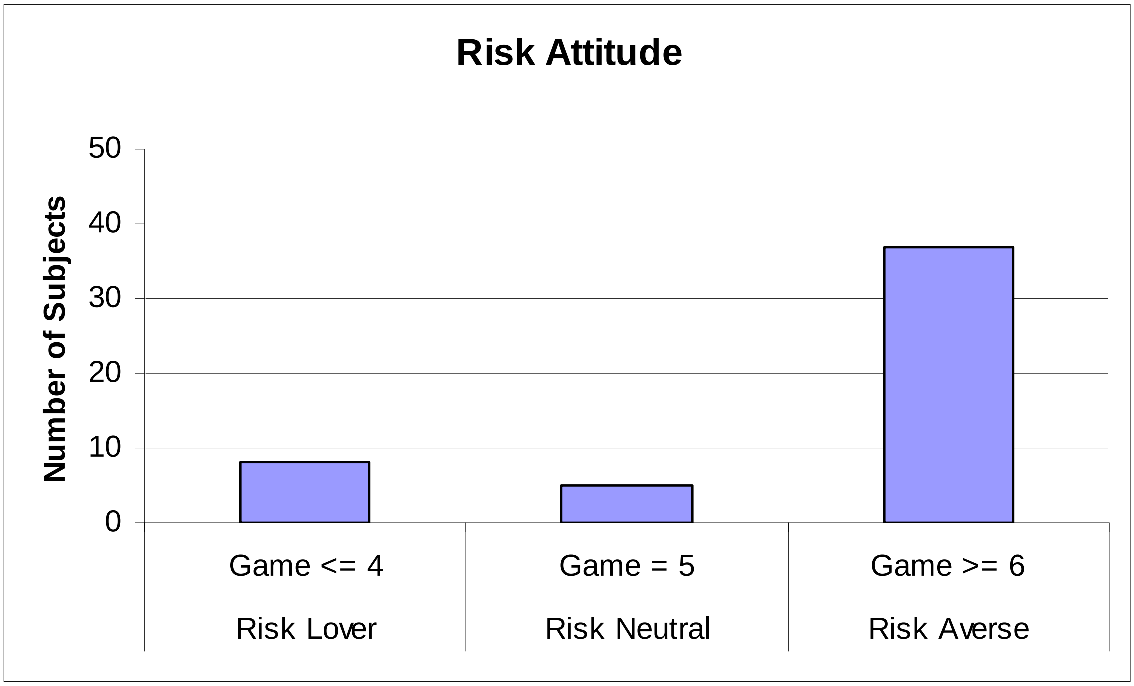

Figure 2. Number of subjects pay to reveal information on the probabilities

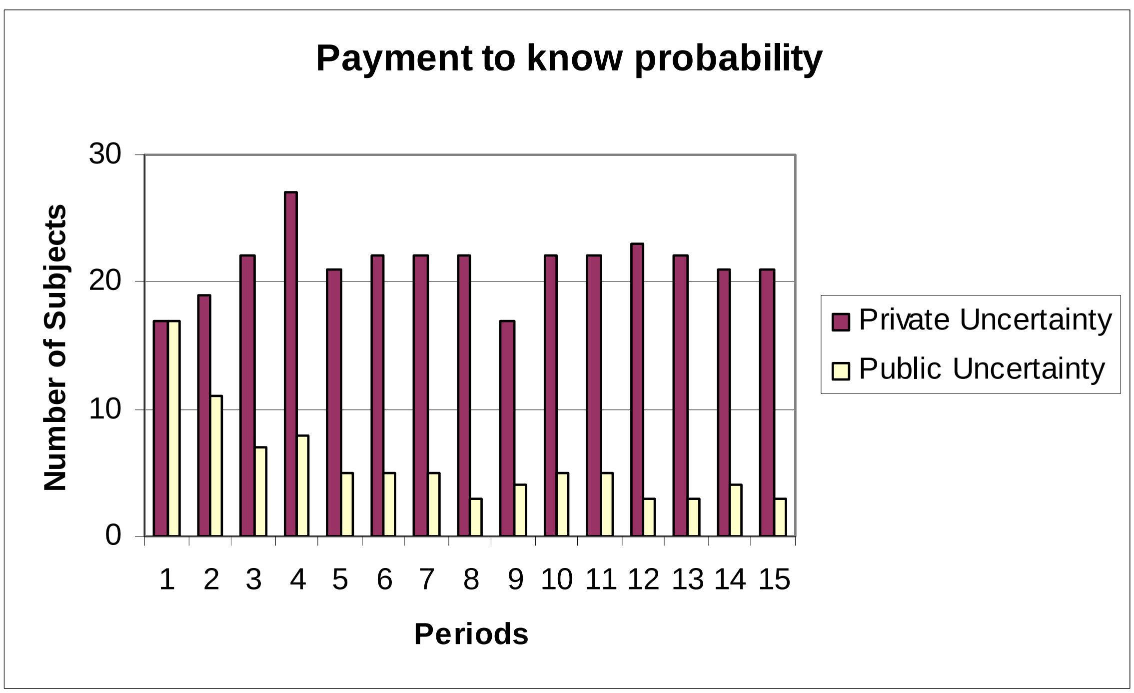

Figure 3 Panel A: Investment patterns in the Uncertainty in Private Goods treatment

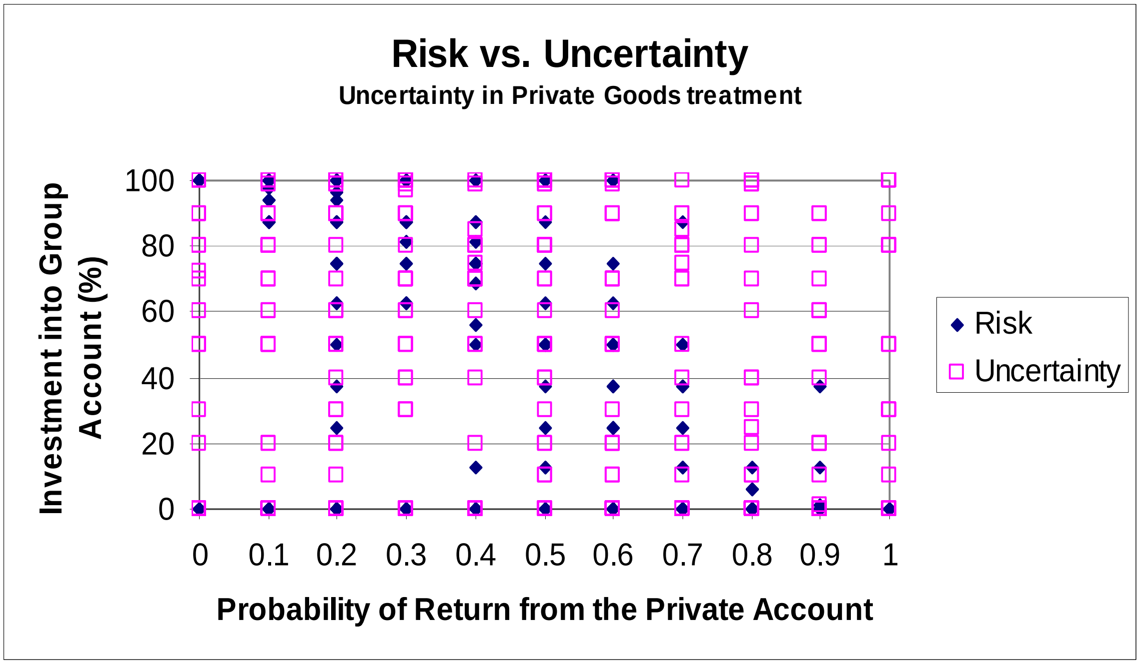

Figure 3 Panel B: Investment patterns in the Uncertainty in Public Goods treatment

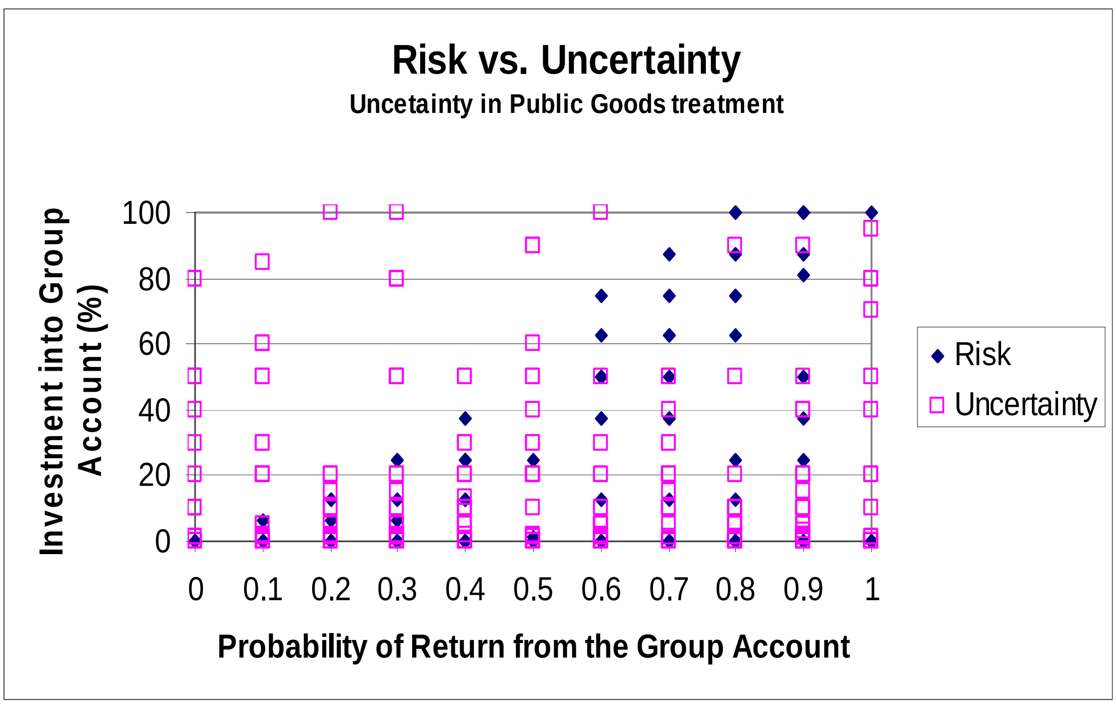

Figure 4 Panel A: Average investment into group account when probabilities are known in the Uncertainty in Private Goods treatment

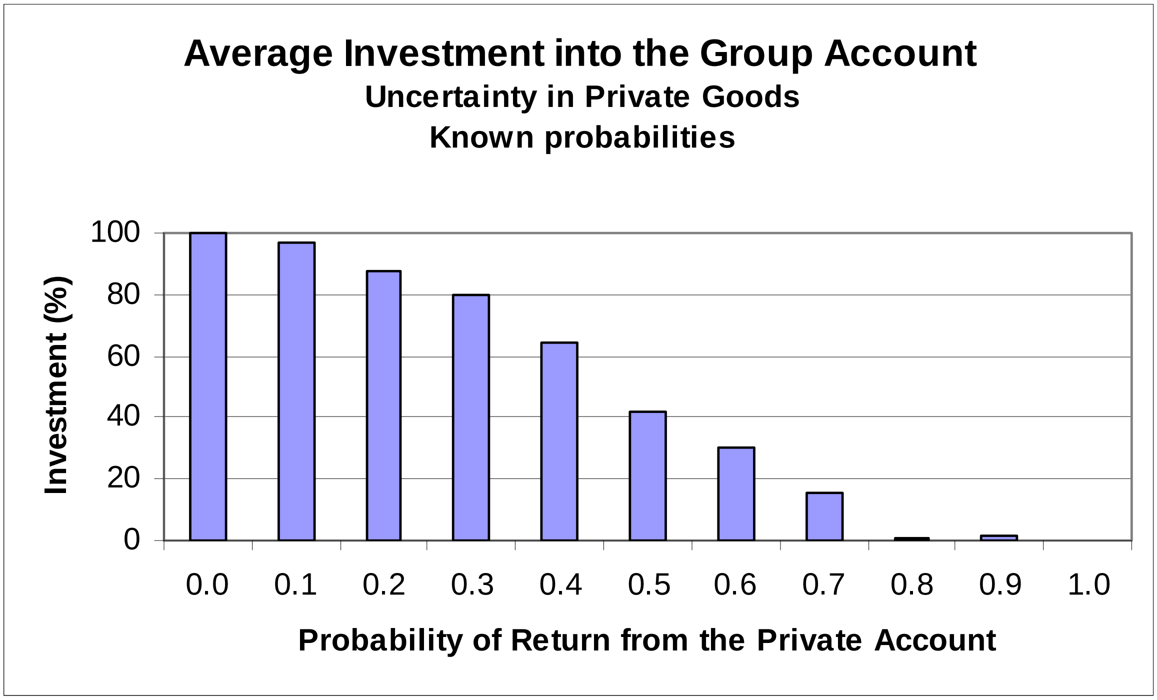

Figure 4 Panel B: Average investment into group account when probabilities are known in the Uncertainty in Public Goods treatment

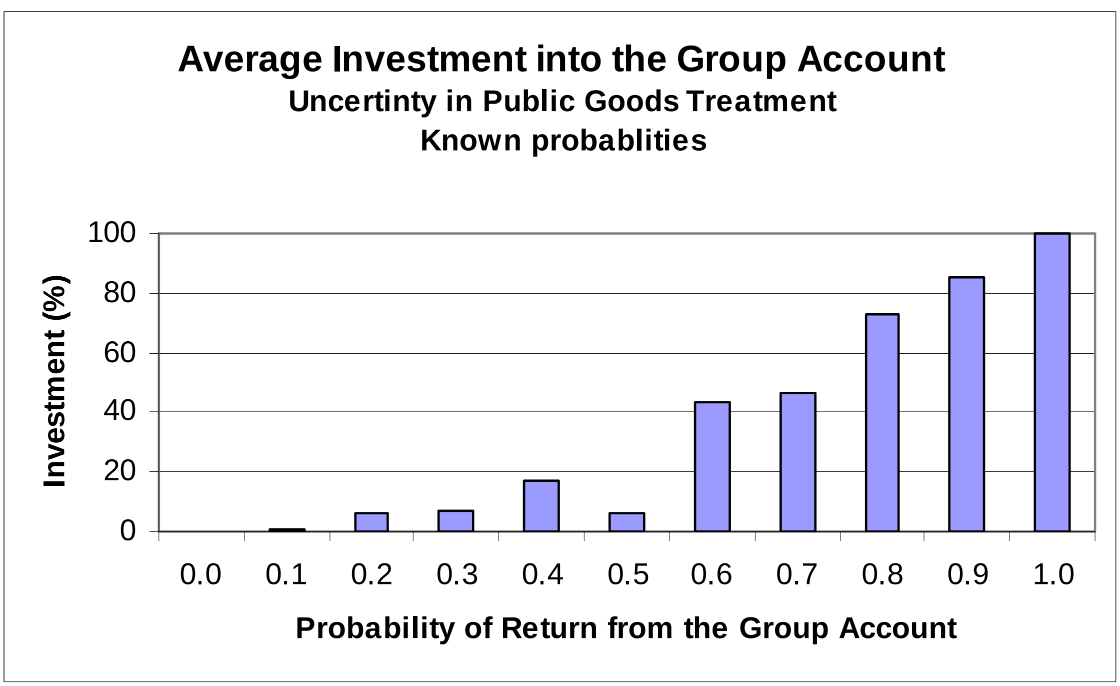

Figure 5. Investment levels separated out by known and unknown probabilities for both treatments