EXPERIMENTAL ANALYSIS OF RISK AND UNCERTAINTY IN PROVISIONING PRIVATE AND PUBLIC GOODS

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This paper uses laboratory evidence from public goods games to examine how in payoff-equivalent situations, decision makers contribute toward private or public goods when they are exposed to different kinds of risks and uncertainties in the provision of these goods. We find that location matters with subjects moving away from the environmental uncertainty in favor of strategic uncertainty when that uncertainty is located on the private good. When the uncertainty relates to the public good, subjects face both kinds of uncertainties on the same good, leading to a significant drop in contributions. An opportunity to reduce uncertainty increases cooperation. (*JEL* C90, D81, H41)

I. INTRODUCTION

This paper investigates how individuals perceive risks and uncertainties when making decisions about private and public goods. Using the framework of public goods games and laboratory experiments, we study whether—in payoff-equivalent situations—decision makers contribute more or less toward private and public goods when outcomes involve different forms of risks and uncertainties.

The economics literature usually applies the term "uncertainty" to describe situations when the probabilities of possible future events are unknown. The term "risk" on the other hand is used to describe situations when the probabilities of future events are known.[1] The presence of uncertainty and risk can be very important in the provisioning of public goods and in policy making. For example, classic public good problems like climate change and depletion of the ozone layer can be thought to differ in the degree of knowledge about the probabilities associated with the events. While climate change is undoubtedly a case of uncertainty since less precise probability estimates exist in either science or economics, the ozone layer depletion can be characterized more as risk since detailed scientific and economic predictions exist about the depletion of the ozone layer and its impact on human health (e.g., melanoma, cataracts). Risk and uncertainty exist in the private domain as well. For example, in the area of individual health, some estimates exist about the correlation between smoking and lung cancer (could be characterized as risk); however, research is still in its infancy on the connection between working with animals and being susceptible to diseases like bird flu (a case of uncertainty).

*The authors are grateful to Ananish Chaudhuri, Pushkar Maitra, Andrew Muller, Charlie Plott, seminar participants at Deakin University, the Australian Conference of Economists, the Experimental Economics Workshop in Sydney, the Indian Statistical Institute in Delhi and Calcutta, Econometric Society Australasian Meetings, Australian National University, and Monash University for their valuable comments on earlier versions of the paper and to Jonathan Payne for his help in running the experiments. Funding from the Australian Research Council is greatly appreciated.

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1. This follows Knight (1921) who introduced the dichotomy of known and unknown probabilities.

ABBREVIATIONS

CPR: Common Pool Resource
GLS: Generalized Least Squares
MPCR: Marginal Per Capita Return

Economic Inquiry
(ISSN 0095-2583)
Vol. 47, No. 1, January 2009, 146–164

doi:10.1111/j.1465-7295.2007.00118.x
Online Early publication January 22, 2008

In addition to the risks and uncertainties mentioned above, the process of policy making involves further uncertainties due to the unknown information about the decisions of others. In the standard noncooperative experimental setting of public goods and common pool resource games, there is always uncertainty about the ultimate size of the public good or resource request, as subjects do not know how other group members will behave. Messick, Allison, and Samuelson (1988) refer to this uncertainty as "strategic uncertainty."[2]

An implicit assumption underlying these public goods and common pool resource dilemma games is that the optimal size of the public good or the carrying capacity of the commons is known and that there is no uncertainty associated with the benefits of the public or private good.[3] However, in many problems, decision makers do not know with certainty the optimal level of public goods or the carrying capacity of the resource. For example, continuing with the example of climate change, the optimal level of carbon dioxide emissions abatement and the costs and benefits of proposed mitigation strategies are not known with certainty. Messick, Allison, and Samuelson (1988, 678–79) introduced the terminology "environmental uncertainty" to distinguish this external factor from strategic uncertainty: "Environmental uncertainty refers to environmental variables that determine which group action is best, while [strategic] uncertainty centres on how other group members will respond... The problem that is raised by the environmental uncertainty is the problem of optimality or efficiency, while the problem raised by [strategic] uncertainty is (...) coordination."

Several researchers have found that the distinction between strategic and environmental uncertainty is important in decision making.[4] Existing literature focuses mainly on uncertainty in common pool resource dilemmas where risk and uncertainty are defined in terms of threshold uncertainty. Messick, Allison, and Samuelson (1988), for example, incorporated a probabilistic destruction of the resource when the safe yield was surpassed. In their experiment, groups of four subjects participated in a single-trial task. If the group total request were below a certain threshold, each group member received his request. If the group total were above the threshold, a coin was flipped to determine whether the members would receive their requests. Messick, Allison, and Samuelson (1988) show that even when strategic uncertainty was absent (i.e., there was only one participant), the random size of the resource led to a suboptimal outcome. Rapoport et al. (1992) used mean-preserving spreads to model increasing environmental uncertainty regarding the size of the common pool resource. The authors found in a five-person common pool resource experiment that subjects dealt with the strategic uncertainty by requesting roughly one-fifth of the mean amount available. As the environmental uncertainty increased, however, subjects requested more than an equal share from the resource. Associated with the observed overexploitation of the common resources, research (Rapoport et al. 1992; Suleiman, Budescu, and Rapoport 1966) suggests that subjects' estimates of the resource size increase as the resource uncertainty increases. One explanation provided by Rapoport et al. (1992) is that people tend to perceive the variability and central tendency of probability distributions

2. The role of strategic uncertainty has been extensively modeled in the laboratory. Several factors including group size (Au and Ngai 2003; Buchanan 1968; Isaac and Walker 1988; Isaac, Walker, and Williams 1990; Loehman, Quesnel, and Babb 1996; Marwell and Ames 1979), the information structure inherent in the experimental design (Au and Ngai 2003; Budescu, Rapoport, and Suleiman 1995a, 1995b; Suleiman, Budescu, and Rapoport 1960), the incentives or contribution mechanism employed (Green and Laffont 1979; Groves and Ledyard 1977, 1980; Loehman, Quesnel, and Babb 1996), implementation of rewards and sanctions (Walker and Halloran 2004), existence and the level of provision point (Isaac, Schmidtz, and Walker 1989; Marks and Croson 1998; Schelling, 1960; Schmidtz, 1987; Suleiman, Budescu, and Rapoport 2001), and incentives for the public good relative to the private good (Isaac and Walker, 1988; Isaac, Walker, and Thomas 1984) have been shown to have a significant impact on the contribution levels. For a survey on treatment variables that affect contribution levels in public goods games, see Ledyard (1995), and for a meta-analysis of several of these factors, see Zelmer (2003).

3. For example, both the theoretical work of Bagnoli and Lipman (1989) and the experiments by Bagnoli and McKee (1991) show that if we offer a group of people the opportunity to contribute to the provision of a public good when the cost of the good, the payoffs to those in the group, and the initial wealth positions of those in the group are all common knowledge, then the Pareto-efficient outcome will emerge if their collective valuations exceed the cost of the public good.

4. Loewenstein, Thompson, and Bazerman (1989) found evidence from experiments that people's attitudes in decision processes involving risk and uncertainty may be very different in social (similar to strategic) and nonsocial (similar to environmental) domains owing to the differences between social and nonsocial preferences.

to be positively correlated. A second explanation is that when people are asked to provide their best estimate of an unknown resource, their estimate will be biased by what they hope for. Such a tendency has been labeled in the literature as "optimism," "outcome desirability bias," or simply "wishful thinking" (Hogarth 1987).[5] While there is extensive research in both the psychological and the economics literature on the effects of resource uncertainty in common pool resource situations under simultaneous and sequential protocols (Budescu, Rapoport, and Suleiman 1995a, 1995b; Gustafsson, Biel, and Gärling 1999, 2000; Rapoport and Suleiman 1992; Rapoport et al. 1992; Suleiman and Rapoport 1988), there is considerably less research on the effects of risk and uncertainty in public goods situations.[6]

Wit and Wilke (1998), for example, investigated the effects of environmental uncertainty (regarding the provision threshold) and strategic uncertainty on contribution to step-level public goods. In the "low–environmental uncertainty" treatment, subjects were informed that the provision threshold would be randomly sampled from a uniform distribution defined over the range [800, 1,000], while in the "high–environmental uncertainty" treatment, the range was increased to [400, 1,400]. The strategic uncertainty was manipulated by giving subjects false information regarding the variance of contributions of others. The authors found lower contributions under high environmental uncertainty with the most dramatic drop in the contribution levels when high environmental uncertainty was coupled with high strategic uncertainty. Au (2004) compared voluntary contributions in a public goods experiment in the case where the provision point was fixed at $m = 3$ to the case where the provision point could take the values $m = 2$, 3, and 4 with equal probability. He found that the provision rate for the public good was significantly higher when the provision point was known precisely. Gustafsson, Biel, and Gärling (2000) compared the voluntary contributions to public goods with the same expected provision threshold but different variances. In general, the average contribution was smaller in the high-variance group. While Wit and Wilke (1998) and Gustafsson, Biel, and Gärling (2000) applied a simultaneous design, Au (2004) replicated these results using a sequential decision-making protocol (i.e., subjects made decisions sequentially). These findings are consistent with the results from common pool resource studies showing that higher environmental uncertainty reduces the rate of intensity of cooperative behavior.

Suleiman, Budescu, and Rapoport (2001), however, report that the effects of environmental uncertainty in the common pool resource and public goods games exhibit qualitative differences. While all studies in the common pool resource dilemma show that individual requests increase with environmental uncertainty, Suleiman, Budescu, and Rapoport (2001) find that the effect of threshold uncertainty is moderated by the threshold mean: contributions to the public good increased as a function of uncertainty for the lower threshold mean and decreased for the higher threshold mean. McBride (2006) and Gustafsson, Biel, and Gärling (2000) also show that outcomes in public good games may be more sensitive to uncertainty and parameter changes compared to common pool resource games. The differential effect of environmental uncertainty in the two types of game was also documented by van Dijk et al. (1999, 111) who concluded that "environmental uncertainty may affect choice behaviour differently

5. An emerging literature on neuroeconomics examines the interactions between experimental economics, neuroscience, and psychology (Camerer, Loewenstein, and Prelec 2005). In this area, researchers attempt to understand decision making in different scenarios, including situations with risk and uncertainty, using medical brain imaging techniques.

6. There is some overlap between research in economics and psychology (see Rabin 1998, for a discussion of some psychological findings that are relevant to economics.) Decision making under risk and uncertainty is an area where the two disciplines have influenced each other. The study of social dilemmas has a rich tradition in both disciplines, with both sides agreeing on main empirical findings. However, they diverge in many other ways; in particular, economists and psychologists would disagree on what they feel needs further explaining (Lopes 1994). For example, experimental economic research and psychological research into the nature of the common pool resource seem to differ. While modeling *renewable* resources in the psychological literature has led to the construction of multistage decision tasks in common pool resource (CPR) games (e.g., Messick and Brewer 1983), modeling exhaustible resources in the experimental economic literature has led to the construction of a sequence of independent single-stage decision tasks (e.g., Hackett, Schlager, and Walker 1994). Exhaustible resources are a special case of renewable resources: where the renewal rate is zero. Budescu, Rapoport, and Suleiman (1995a, 172) conclude that the reason they are treated differently "may reflect the fact that, *psychologically*, the two cases seem to include different perspectives (frames), and invoke distinct considerations in the appropriators' minds."

in public good dilemmas, than in resource dilemmas."[7]

Very little research has been conducted to examine the impact of endogenous probabilities in these social dilemma games. In the common pool resource experiments of Walker and Gardner (1992), the probability of destruction of the resource was an increasing function of total group exploitation of the commons, and such destruction ended the experiment. The authors found that in a decision environment with well-defined probability and significant opportunity costs of destruction, efficiency was very low (21%) and the resource was quickly destroyed (longest experiment consisted of six periods). Using members' individual effort in a team sport as a motivation, Dickinson (1998) conducted a public good experiment where he introduced environmental uncertainty as an endogenous probability of provision into the voluntary contributions mechanism—the provision of the public good (winning in the sports event) was conditional on the aggregate contribution level. The author found that the increase in probability as a function of contribution levels, *per se*, did not significantly affect contribution levels (only through the increase in marginal incentives to contribute). In another experiment, Dickinson (2001) measured the efficiency-improving properties of giving incentives in a public good game where monetary prizes were given to high contributors defined both in terms of absolute contributions and then in terms of relative ability (relative to initial endowment). Results show that such private incentives increased the efficiency levels by 10%–25%.

In this paper, we explore, using laboratory experiments, how environmental and strategic uncertainties when coupled together influence decisions in the context of the provision of public and private goods. This paper makes several contributions. While previous research has examined different aspects of risk and uncertainty in isolation and often in a common pool resource setting, this paper distinguishes between risk and uncertainty and between variability in public versus private goods in a standard public good setting. Complimenting the literature on common pool resource dilemmas where uncertainty is defined in terms of threshold uncertainty, this paper defines risk and uncertainty in light of different probability distributions. The treatments considered allow us to isolate strategic uncertainty from several forms of environmental risk and uncertainty using known (environmental risk treatments), unknown (environmental uncertainty treatments), and endogenous (incentives treatments) probabilities. In the baseline treatment, no environmental uncertainty exists and only strategic uncertainty influences the outcome. Throughout the rest of the treatments, strategic uncertainty (e.g., group size, communication, marginal incentives to contribute) is kept constant and environmental risk and uncertainty are introduced in both private and public goods settings. A within-subject design and a multiple-period game allow us to examine these areas of research in a systematic manner to gain further insights into different aspects of decision making.

The current design was chosen to allow for comparison with existing research but also to ensure that the effects of different kinds of environmental uncertainty, on the contribution levels, are isolated. While Wit and Wilke (1998) manipulated the strategic and environmental uncertainty simultaneously, we keep the strategic uncertainty constant across treatments in order to study the effects of environmental uncertainty. Also, while previous research defined the environmental uncertainty by increasing the range from where the threshold of the provisioning of the public good was drawn (Wit and Wilke, 1998) or the range of the possible size of the common pool resource while keeping the expected values constant (Rapoport et al. 1992), we model the environmental uncertainty by defining different forms of probability distributions. Furthermore, we implemented a simultaneous decision protocol and a continuous public good framework, as opposed to a step-level public good. Also, similar to the incentives treatment in Dickinson (1998), we introduce endogenous probability and extend it to the provisioning of both the private and the public goods in two separate treatments.

II. EXPERIMENTAL DESIGN

A. Experimental Procedure

The laboratory experiment was implemented in ten sessions each involving 5 subjects

7. For further discussion of the different kinds of environmental and strategic risk and uncertainty studied in the literature, in various experimental settings, refer to Nemes (2005).

and 15 decision-making periods for each of the seven treatments.[8] We used a within-subject design; all 50 subjects participated in the seven treatments, which allowed for powerful comparisons across treatments. This design also allowed us to keep all elements of strategic uncertainty constant across treatments as the same five subjects interacted in different treatments. At the beginning of each experimental session, participants were told that they would be participating in an economic experiment in which they would make investment decisions. A group of five participants faced the same investment dilemma and made simultaneous decisions. Each subject participated only once in the experiment, that is, they participated in one session only.

In order to control for risk aversion at the individual level, prior to the computerized experiment, we asked the subjects to participate in a hand-run lottery game. Participants had to indicate their preferences between two options: a safe option that yielded \$7 with certainty or a risky option. The risky option had a probability of winning \$12 changing from 10% in the first lottery to 100% in the tenth lottery or correspondingly, the probability of winning \$2 changing from 90% in the first lottery to 0% in the tenth lottery (similar to lottery games described in Brown and Stewart 1999; Holt and Laury 2002). One of the games on the sheet was played at the end of each session. Using the information on when subjects switch from the risky option to the safe option, we can define whether they are risk lovers, risk neutral, or risk averse. Subjects who switch before or at the fourth lottery are classified as risk lovers. Subjects who switch at the fifth lottery are risk neutral, and subjects who switch after the fifth lottery are risk averse. Conducting the lottery game, therefore, helped in measuring 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 in the group context.[9] Furthermore, qualitative and quantitative information were also collected in the form of questionnaires from the participants. The participants completed these questionnaires after Treatments 4 and 5 and also at the end of the session. (The instructions and questionnaires are available from the authors.)

The experiments were conducted using subjects drawn from a population of undergraduate and graduate students at the University of Melbourne. Subjects made an average of 33 cents per decision period and a total of \$37 on average. Furthermore, subjects received an additional \$2, \$7, or \$12 depending on their choice and the outcome of the lottery game. In order to control for wealth effects, their income from the lottery game was only revealed to the subjects at the end of the session.

B. Decision Process

At the start of each period, each subject was given the same number of tokens or experimental dollars, 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 with probability p_x to the individual only. Contributions to the group account earned $\beta G/n$ experimental dollars to each participant with probability p_g, where $G = \sum_{i=1}^{n} g$, β is the "efficiency factor" of the group account, and n is the number of participants in the group. Contributions to the group account yielded the same return to all participants irrespective of their contributions. Therefore, the group account exhibited the public goods' nonexcludible and nonrival characteristics. At the end of each period, subjects learned the aggregate level of contribution to the public good and their return from the private as well as the group accounts.

C. Formulation of the Social Dilemma

Individual *i*'s expected payoff is given by $E(u_i) = p_x \alpha x_i + p_g \beta G/n$. The subjects must maximize this payoff 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 nonnegativity constraint ($g_i \geq 0$).

Let us 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.[10] EM is the expected value of the MPCR:

8. The experiment was programmed and conducted with the software *z*-Tree (Fischbacher 2007).

9. While the risk attitude survey was an important part of the current research and we use the risk estimates in the multivariate estimations presented in the Results section, the results are discussed in further detail in Nemes (2005).

10. It can also be seen as the marginal rate of substitution of the private good for the public good or as a measure of the incentives to contribute to the public good.

TABLE 1
Treatment Parameterization

Treatment		α	β	p_x		p_g	
Baseline	1	1	1.5	1	Known	1	Known
Risk	2	2	1.5	0.5	Known	1	Known
	3	1	3	1	Known	0.5	Known
Uncertainty	4	2	1.5	$p_x = r_x$, uniform distribution, $r_x \in (0,1)$	Unknown, unless requested	1	Known
	5	1	3	1	Known	$p_g = r$, uniform distribution, $r_g \in (0,1)$	Unknown, unless requested
Incentives	6	2	1.5	$p_{xi} = r_x + f(x_i)$	Unknown	1	Known
	7	1	3	1	Known	$p_g = r_g + f(G)$	Unknown

$$\mathrm{EM} = E(M) = -E(\partial u_i/\partial G)/(\partial u_i/\partial g_i) = \beta p_g/n\alpha p_x.$$

In the baseline treatment, $p_x = p_g = 1$ and $\mathrm{EM} = M$. The values of α and β may change from one treatment to the other but remain constant throughout each treatment.

The social dilemma arises if the parameters satisfy the inequality:

$$0 < \beta p_g/n < \alpha p_x < \beta p_g.$$

In this case, a unit investment into the private account provides a subject with more payoff than a unit investment into the group account. On the other hand, taking a unit of the private investment from every participant and contributing it to the group account make each participant better off. Thus, the unique dominant strategy is to free ride (i.e., zero contribution, $g_i = 0, \forall i$), while the socially optimal Pareto-efficient solution requires every participant to contribute all his or her tokens to the group account (i.e., $g_i = \omega_i, \forall i$).

D. Treatments

We examine seven treatments in this paper. We controlled for order effects by switching the order in which subjects experienced the treatments.[11]

11. In keeping with other papers in this area (Dickinson 1998; Wit and Wilke, 1998), we used a within-subject design. The baseline treatment was always conducted first, and the risk, uncertainty, and incentives treatments followed in the same order. We used this ordering pattern specifically to ensure that subjects were familiar with the simple treatments before they made decisions in the more complex treatments. The order of the treatments varied in the sense whether it was the private or the public good that had risks or uncertainties associated with it. On analysis of the data, we do not find any evidence of ordering effects.

Baseline (Treatment 1). The baseline treatment (Treatment 1) is a standard public goods game; there is no risk regarding return from the private or the group account. All parameters (α, β, p_x, and p_g) are known with certainty to the participants and $p_x = p_g = 1$, $\alpha = 1$, $\beta = 1.5$. There is no environmental uncertainty, and the only uncertainty that is present in the game is strategic uncertainty, which is kept constant throughout the following treatments. The expected marginal per capita ratio is $\mathrm{EM} = M = 0.3$. The group payoff in case of the Pareto-efficient outcome would be 1.5 experimental dollars for each group member for each period, while the free-riding Nash equilibrium would yield each subject 1 experimental dollar per period. The parameters for $n = 5$ and $\omega_i = 100$ are summarized in Table 1.

Environmental Risk (Treatments 2 and 3). In the risk treatments, the probability of obtaining the return from the private account (Treatment 2) or the group account (Treatment 3) is drawn from a Bernoulli distribution while keeping everything else constant (including the expected value of the marginal incentives to contribute). Participants are no longer guaranteed the return from their investments. In Treatment 2, the probability of return from the private account is reduced to $p_x = 0.5$, but it is held constant throughout the treatment and all participants know its value. For each period, the computer generated a random number, $r \in [0,1]$. If $r \leq p_x$, then the investment multiplied by the efficiency factor on the private account (αx_i) was returned. Otherwise the investment into the private account was lost to the participants. The investment into the group account was returned with certainty $p_g = 1$, and the efficiency factor on the group account remained unchanged at $\beta = 1.5$.

Similarly, in Treatment 3, the return from the group account is no longer guaranteed, but its probability $p_g = 0.5$ is held constant and is known to all participants. In order to preserve the value of EM = 0.3 and maintain the single-period dominant strategy of zero contributions and the Pareto-efficient outcome at 100% contribution, the efficiency factor on the private and group accounts was modified to $\alpha = 2$ and $\beta = 3$ in Treatments 2 and 3, respectively. The parameters of the group account were held at the values of the baseline treatment, $p_x = 1$ and $\alpha = 1$. Similar to Treatment 2, the return from the group account was determined by random number generation.[12]

Environmental Uncertainty (Treatments 4 and 5). In Treatments 4 and 5, the probability of receiving the return from the investment is drawn from a uniform distribution in each period and is not displayed to participants. Therefore, there is uncertainty regarding the return from the investment into the private (Treatment 4) and group (Treatment 5) accounts. 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) and group (p_g) accounts is displayed on the computer screen in Treatments 4 and 5, respectively. This probability is the private information of those participants who paid the fee for the information, and they remain with $\omega_i - f = 80$ tokens to invest in the period.[13]

12. The environmental risk treatments can be thought to model decisions where, based on past events and statistical analysis, decision makers can estimate the possible outcomes and the probability of occurrence of these outcomes. For example, several studies have been undertaken to estimate the costs, health-related benefits, and associated probabilities of certain automobile emissions standards (like clean fuels, banning lead additives, reduction of carbon monoxide and volatile organic compounds). Decisions in such cases are usually based on known probabilities, that is, in the face of risk.

13. Ideally it would have been interesting to have uncertainty treatments in which subjects could not choose to convert uncertainty into risk and then add treatments in which that option was available to them. This would have increased the number of treatments and would have been very difficult to accommodate within the 2-h experimental slot. Hence, we chose the potentially more interesting (and policy-relevant) treatment where subjects were given the choice to pay to convert uncertainty into risk.

Treatments 4 and 5 allow us to divide the participants into two distinct groups: those who know the exact value of the probability (facing risk) and those who do not (facing uncertainty). Treatments 4 and 5 capture scenarios when the probabilities of the benefits or costs of an outcome are initially uncertain. An example for Treatment 4 could be a building inspection, where architects can inspect a building for a prospective buyer, for a fee, and convert uncertain situations into risky situations. We can interpret Treatment 5 as a setup where decision makers may invest in research in order to get clearer estimates about the probabilities. Research, however, is costly and will leave decision makers with less money to invest into the public good itself.

At the end of Treatments 4 and 5, 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 and group accounts, respectively.

Incentives (Treatments 6 and 7). In Treatments 6 and 7, participants have the opportunity to increase the probability of return from the private and group accounts, respectively. In Treatment 6, participants face an uncertainty regarding the probability of return from the private account. Similar to the previous treatments, the probability initially is drawn from a uniform distribution. Participants, however, due to their individual investments into the private account, could increase the probability of return from the private account. Similarly, in Treatment 7, a higher level of aggregate investment into the group account may lead to the increase of the initial probability of return from the group account. The probability of return in each round is determined by the sum of a random number drawn from a uniform probability distribution and an increment due to the investment into the private (Treatment 6) or group account (Treatment 7) in that round. That is, $p_{xi} = r(1 + x_i/2\omega)$ and $p_g = r(1 + G/2n\omega)$, respectively.

In Treatment 6, therefore, depending on the individual investments, the participants may face differing levels of probabilities. Both the initial random number and the probability increment remain unknown to the participants until the end of the period. They do know, however, that they can increase the probability by increasing their contributions. At the end of each period, the computer displays the initial

TABLE 2
Total and Mean Investment into the Private and the Group Accounts

	Investment into the				
	Private Account		Group Account		
Treatment	**Total**	**Mean**	**Total**	**Mean**	**Standard Deviation (Private and Group Accounts)**
1	56,539	75.39	18,461	24.61	32.66
2	36,449	48.60	38,551	51.40	38.26
3	65,664	87.55	9,336	12.45	21.74
4	41,230	54.97	33,770	45.03	41.90
5	67,269	89.69	7,731	10.31	22.89
6	63,928	85.24	11,072	14.76	26.07
7	62,976	83.97	12,024	16.03	28.31
Total	39,4055	75.06	130,945	24.94	

probability and the increase in probability of return from the private and group accounts in Treatments 6 and 7, respectively.[14]

In summary, in Treatments 2–7, we vary environmental risk and uncertainty on the private and group accounts while keeping the strategic uncertainty and the expected payoff (together with the expected value of the marginal incentives to contribute) equivalent to those in the Baseline treatment.

E. Hypotheses

We use the design described above to test the following hypotheses to verify and extend the behavioral evidence in decision making under risk and uncertainty.

> Hypothesis 1: In payoff-equivalent situations, subjects contribute less to the public good when risk or uncertainty is associated with the public good than when risk or uncertainty is associated with the private good (comparing Treatment 2 with 3 and Treatment 4 with 5).
>
> Hypothesis 2: In payoff-equivalent situations, subjects contribute more to the public good when they face endogenous probability of provision of the public good than when they face endogenous probability of provision of the private good (comparing Treatment 6 with 7).
>
> Hypothesis 3: In payoff-equivalent situations, subjects' contribution level to the public good is higher when facing uncertainty than when facing risk, both associated with the private good (comparing Treatments 2 and 4).
>
> Hypothesis 4: In payoff-equivalent situations, subjects' contribution level to the public good is lower when facing uncertainty than when facing risk, both associated with the public good (comparing Treatments 3 and 5).
>
> Hypothesis 5: In payoff-equivalent situations, when probabilities are endogenous, that is, subjects can increase the probability of provision of the private good, subjects' contribution to the public good is lower than that when facing uncertainty associated with the private good (comparing Treatment 6 with 4).
>
> Hypothesis 6: In payoff-equivalent situations, when probabilities are endogenous, that is, subjects can increase the probability of provision of the public good, subjects' contribution to the public good is higher than when facing uncertainty associated with the public good (comparing Treatment 7 with 5).

III. RESULTS

We start with an overview of the data collected from the experiments and then report results from econometric tests, which examine the impact of risk, uncertainty, and incentives on individual behavior.

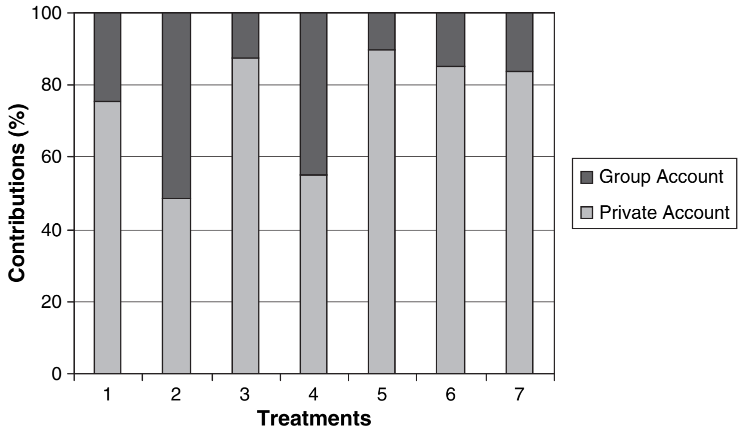
A. Overview

Table 2 and Figure 1 present the average proportional contributions to the private and the public goods as a percentage of their endowments for all treatments.[15] The dark

14. The incentives treatments mainly reflect cases when technological advancement increases the probability of obtaining the benefits from the project. Treatment 7 models cases where innovations have an impact on a public scale, and Treatment 6 captures cases where the reward for innovation has a private characteristic.

15. In the uncertainty treatments (Treatments 4 and 5), subjects may choose to pay a fee of 20 experimental dollars from their endowment to reveal the probability associated with the private and the public good, respectively. The proportional contribution takes account of the fact that in these two treatments, some subjects have only 80 experimental dollars to place in the private and group accounts.

FIGURE 1
Proportional Contributions into the Private and the Group Accounts



parts of the columns in Figure 1 illustrate the proportion of the endowment contributed to the public good. In all treatments except 2 and 4, the contribution to the public good is approximately 20%. In Treatments 2 and 4, where there is risk or uncertainty associated with the private good, the average contribution toward the public good reaches approximately 50%. Subjects seem to move away from the risky or uncertain private good and contribute more toward the public good.

Figure 2 tracks the average contributions to the public good over the 15 periods in each treatment and confirms the much higher contributions in Treatments 2 and 4. Contributions start at a higher point and gradually taper down by the end of the session. Figure 3 depicts the deviation from the baseline treatment. Since the baseline treatment (Treatment 1) is a pure strategic uncertainty treatment (there is no environmental uncertainty) and the strategic uncertainty is kept constant throughout Treatments 2–7, the deviation from the baseline treatment could be considered to be solely the effect of the environmental risk and uncertainty. Except in Treatments 2 and 4, when the risk and uncertainty are related to the return from the private good, the contribution levels are below that in the baseline treatment.

FIGURE 2
Average Contribution Levels over the 15 Periods

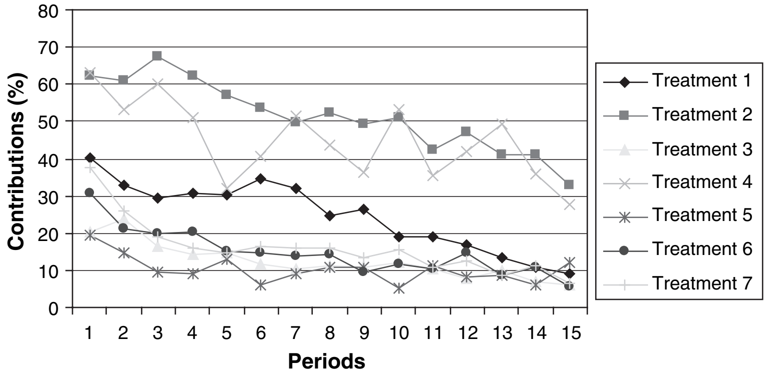


FIGURE 3
Average Contribution Levels Relative to the Baseline Treatment

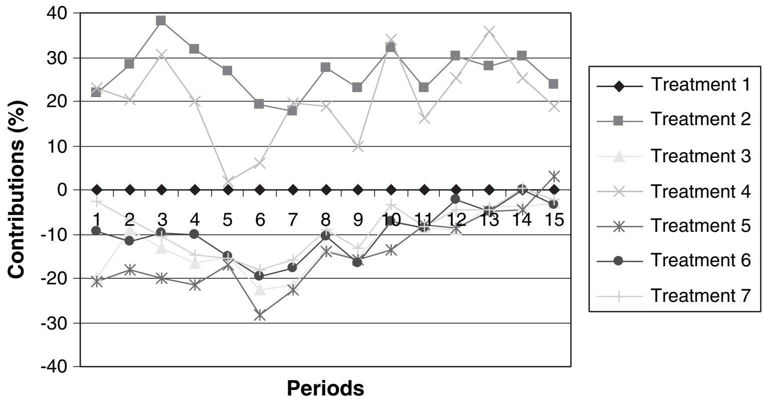
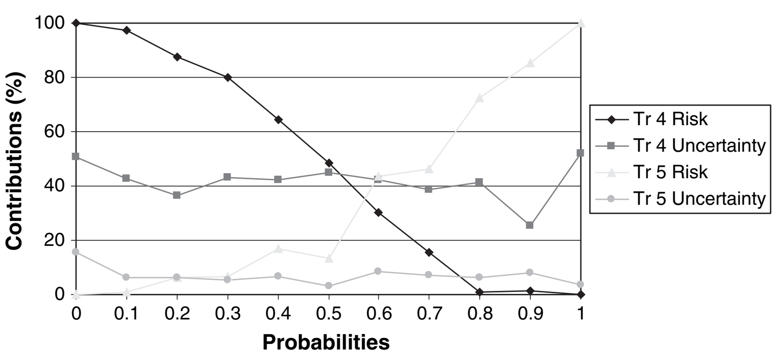


Figure 4 shows the decisions made by subjects under risk (i.e., known probability) and uncertainty (i.e., unknown probability) in Treatments 4 and 5. Note the difference in the pattern of contributions when risk is introduced to the provisioning of the private good (Treatment 4, marked by diamond shape) versus public good (Treatment 5, marked by triangles). As the probability of providing the private good increases, subjects contribute less to the public good and at $p_x = 0.8$, subjects contribute almost 0% to the public good. When risk is introduced in the provisioning of the public good, subjects divert away from contributing to the public good. Only when the probability of providing the public good is very high do subjects start to contribute, and 100% contribution levels are achieved when the probability of providing the public good is 1. Similarly, there is a difference in the patterns of contributions when subjects face uncertainty (unknown probability) related to the private good (Treatment 4, rectangular shapes) and when they face uncertainty related to the public good (Treatment 5, round shapes). Regardless of what the actual probabilities are, subjects facing uncertainty contribute around 50% to the public good when uncertainty is associated with the private good. When uncertainty is associated with the public good, however, contribution levels drop to around 5%.

FIGURE 4
Contributions to the Group Account with Environmental Risk and Uncertainty (Treatments 4 and 5)



In Treatment 4, in 43% of the cases, subjects are willing to pay the fee of 20 experimental dollars to reveal the probability of return from the private good. In Treatment 5, subjects on average pay for information 12% of the time.[16] Though not recorded in Figure 4, it is interesting to note that a few of these subjects did not seem to use the revealed information in their decision making. For example, even when the probability of return from the private good was very low ($0 \leq p_x \leq 0.3$) or the probability of return from the public good was very high ($0.7 \leq p_g \leq 1$), these subjects invested either all or a substantial part of their remaining tokens into the private good. The interesting aspect is not their investment decision, *per se*, but the fact that they were willing to pay for the information about the probabilities but then not use this information in their decision making. The above cases could be understood as examples of aversion from strategic uncertainty. So even when environmental probabilities are unfavorable, they are still more attractive than strategic uncertainty (i.e., contribution to the public good).

B. Econometric Tests

To examine whether our data support the six hypotheses outlined above, we present results from very conservative pairwise *t*-tests and nonparametric Wilcoxon rank-sum tests in Table 3. These statistical tests use one observation per treatment per session. The nonparametric tests are particularly valuable, as they require a minimum of statistical assumptions. In addition, we also report results from multivariate regression models. The regression models evaluate the contribution of different factors on the decisions made by subjects. These panel regressions employ a random effects error structure, with the subject representing the random effect. We also cluster the errors at the group level to capture any unobserved heterogeneity in the group.

We present results from random effects generalized least squares regressions with clustering, where the dependent variable is the

TABLE 3

Pairwise *t*-Tests and Nonparametric Wilcoxon Rank-Sum Tests for the Difference in Means

Treatment	1	2	3	4	5	6
2	3.379*** (2.721***)					
3	−1.873* (−1.739*)	−5.790*** (−3.628***)				
4[a]	2.899*** (2.343***)	−1.792* (−1.890*)	5.758*** (3.780***)			
5[a]	−2.237** (−2.192**)	−6.197*** (−3.704***)	−1.108 (−1.058)	−6.265*** (−3.780***)		
6	−1.540 (−1.285)	−5.521*** (−3.704***)	0.478 (0.680)	−2.755** (−2.343**)	0.947 (0.983)	
7	−1.140 (−1.361)	−4.562*** (−3.099***)	0.570 (0.151)	−4.236*** (−2.948***)	1.447 (1.512)	0.205 (−0.151)

Notes: The pairwise estimates use the horizontal as the comparison base. The 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.

[a]In Treatments 4 and 5, we only include subjects who do not want to know the probability they face.

*Significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

16. This difference (43% vs. 12%) is statistically significant. Also subjects' willingness to pay, obtained from the questionnaires after Treatments 4 and 5, reveal that they were willing to pay significantly more to convert uncertainty into risk when the uncertainty was associated with the private good (17% vs. 9% of their endowment).

TABLE 4
Summary of Variables Used in the Regressions

Variable	Description	Mean	Minimum	Maximum
Prop_pubaccount	The proportional contribution to the public account as a percentage of the endowment	0.25	0	1
Loutcome	Lag of the outcome variable (outcome = 1 if good was provided)	0.60	0	1
Ldeviation	Difference between the amount contributed to the public good by an individual in the previous period and the average group contributions in the previous period	99.79	0	400
Sex	=1 if female	0.42	0	1
Age	Age of the subjects	22.5	18	45
Risk_Averse	Subjects who switch after the fifth lottery	0.74	0	1
Risk_Neutral	Subjects who switch at the fifth lottery	0.10	0	1
Risk Lover	Subjects who switch before or at the fourth lottery	0.16	0	1
EM	The expected marginal per capita ratio	0.64	0	226.59
lprobincr	The increase in probability achieved in the previous period by the contributions in Treatments 6 and 7	8.68	0	33

individual contribution made to the public good as a proportion of the endowment.[17] Apart from the treatment dummy, the other regressors included are inverse of time period (invperiod) to capture the dynamic elements of the data ($1/t$); whether the random outcome was such that it resulted in the provision of the private or public good in the previous period, captured by a binary variable (loutcome); the difference between the amount contributed to the public good by an individual in the previous period and the average group contribution in the previous period (ldeviation); the increase in probability achieved in the previous period by the investments in Treatments 6 and 7 (lprobincr); the expected marginal per capita ratio (EM); and individual-specific characteristics.[18] The individual characteristics are age, gender, and their attitudes toward risk as measured by the lottery game conducted before the public goods experiment. As explained in the Experimental Design section, we classified subjects into three categories: risk averse, risk neutral, and risk lovers, using the results obtained from the lottery game. This is an individual-specific risk measure and allows us to control for their risk attitudes. We define dummies for risk-averse and risk-neutral subjects and include these in the regression. The variables used in the regressions are summarized in Table 4.

Since subjects participated in the seven treatments in different order, we conducted statistical tests to determine if the order in which they participated had an impact on contribution levels in the different treatments. Whether subjects participated in Treatment 2 or 3 first did not lead to significant differences in contributions in the two treatments (probability value = .98). Similarly, the order for Treatments 4 and 5 (probability value = .85) and Treatments 6 and 7 (probability value = .95) did not have any significant behavioral implications.

Tables 5, 6, and 7 report results from pairwise regressions, and Table 8 presents results from pooled regressions where we include the data for all the treatments and introduce treatment dummies (T2–T7), with Treatment 1 as the baseline dummy, to examine how subjects behave in the different treatments. In Table 8, we show results from different model

17. We also conducted random effects tobit regressions in which the dependent variable is censored and takes values between 0 and 1. The results are similar to the Generalized Least Squares (GLS) estimates.

18. The explanatory variables used to understand behavior vary depending on the treatments being considered. For example, lprobincr is used only when comparing Treatments 6 and 7 and EM is used only when comparing Treatments 2 and 4 and Treatments 3 and 5 in regressions where we separate the data for subjects who want to know the probability they face.

TABLE 5
Random Effects GLS Estimates for the Individual Contribution Levels: Pairwise Regressions, Testing Hypotheses 1 and 2

	Treatments 2 and 3	Treatments 4 and 5	Treatments 6 and 7
Invperiod	0.4607*** (0.0518)	0.2654*** (0.0899)	0.3204*** (0.0796)
Treatment	−0.3883*** (0.0518)	−0.3412*** (0.0469)	0.0307 (0.0507)
Loutcome	0.0425*** (0.0213)	0.0053 (0.0293)	−0.0118 (0.0201)
Ldeviation	0.0047*** (0.0007)	0.0038*** (0.0009)	0.0044*** (0.0010)
Sex	−0.0002 (0.0439)	0.0277 (0.0368)	0.0246 (0.0297)
Age	−0.0001 (0.0031)	0.0029 (0.0025)	0.0102*** (0.0030)
Risk_averse	0.0166 (0.0462)	0.0166 (0.0470)	−0.0347 (0.0352)
Risk_neutral	0.0432 (0.0659)	0.1506*** (0.0552)	0.0724 (0.0661)
Lprobincr			0.0024 (0.0016)
Constant	0.3944*** (0.1105)	0.2868*** (0.0950)	−0.1629** (0.0621)
Observations	1,400	1,400	1,400
Sigma_u	0.1079	0.0883	0.0982
Sigma_e	0.2308	0.2825	0.1828
Rho	0.1792	0.0890	0.2240

Notes: Numbers in parentheses are robust standard errors.
**Significant at the 5% level; ***significant at the 1% level.

specifications, which are reported to indicate the robustness of the results.[19] The pooled results are consistent with the pairwise regressions reported. Table 9 summarizes the results for all the hypotheses.

Results relating to the first two hypotheses are reported in Tables 3 and 5. These hypotheses examine the impact of the location of the risk and uncertainty, that is, whether it is associated with the private or the public good. Both the statistical tests (*t*-tests and the Wilcoxon tests) and the regression results provide strong support for Hypothesis 1, that is, in payoff-equivalent situations, subjects contribute less to the public good when risk or uncertainty is associated with the public good than when risk or uncertainty is associated with the private good. The dummies for Treatment 3 (in the regressions comparing Treatments 2 and 3) and Treatment 5 (in the regressions comparing Treatments 4 and 5) are negative and statistically significant. Applying a threshold uncertainty design, Wit and Wilke (1998), Au (2004), and Gustafsson, Biel, and Gärling (2000) find that as uncertainty thresholds increase, contribution to the public good declines.[20] Our results from Hypothesis 1 are consistent with these previous studies and show that in a continuous public good setup, increased environmental variability reduces cooperation.

Hypothesis 2, that is, in payoff-equivalent situations, subjects contribute more to the public good when they face endogenous probability of provision of the public good (Treatment 7) than when they face endogenous probability of provision of the private good (Treatment 6), is not supported by the data. The statistical tests and the regressions show that the average contributions to the public good are higher in Treatment 7 than in Treatment 6, although the difference is not statistically significant. This is the only treatment in which even though subjects face uncertainty in the public good, they contribute about the same as they do when they face uncertainty in the private good (Treatment 6). This is

19. Model 1 in Table 8 includes only time and the treatment dummies, Model 2 adds lagged variables (loutcome, ldeviation), and Model 3 adds the individual-specific characteristics. The results are robust to these additions. We also conducted these robustness tests for the pairwise regressions reported in Tables 5, 6, and 7 but do not present them in the paper to conserve space. Again, the results are robust to different model specifications.

20. Suleiman (1997) shows in a theoretical framework that threshold uncertainty in public good games can lead to lower contributions. McBride (2006) predicts that the effect of uncertainty in these games depends on the value of the public good, with a higher value leading to an increase in contributions. However, these predictions receive weak support in the experiments (McBride 2007).

TABLE 6
Random Effects GLS Estimates for the Individual Contribution Levels: Pairwise Regressions, Testing Hypotheses 3 and 4

	Treatments 2 and 4		Treatments 3 and 5	
	GLS[a]	GLS[b]	GLS[a]	GLS[b]
Invperiod	0.5129*** (0.0731)	0.4568*** (0.1038)	0.2212*** (0.0784)	0.2890*** (0.0840)
Treatment	−0.1134* (0.0581)	−0.1633*** (0.0456)	−0.0411 (0.0279)	0.1062*** (0.0333)
Loutcome	0.0786** (0.0371)	0.0618** (0.0292)	−0.0096 (0.0107)	−0.0209 (0.0143)
Ldeviation	0.0032*** (0.0006)	0.0026*** (0.0007)	0.0035*** (0.0006)	0.0035*** (0.0005)
Sex	0.0135 (0.0783)	0.0153 (0.0889)	0.0121 (0.0363)	−0.0064 (0.0407)
Age	0.0030 (0.0080)	0.0002 (0.0073)	0.0003 (0.0016)	0.0010 (0.0019)
Risk_averse	0.0662 (0.0699)	0.0683 (0.0809)	−0.0269 (0.0408)	−0.0287 (0.0448)
Risk_neutral	0.0748 (0.1166)	0.1004 (0.1059)	0.0403 (0.0287)	0.0499 (0.0388)
EM		0.7325*** (0.0818)		1.7056*** (0.2745)
Constant	0.2512 (0.1926)	0.1080 (0.1797)	0.0915 (0.0727)	−0.4336*** (0.0766)
Observations	1,097	986	1,329	771
Sigma_u	0.1522	0.1459	0.0605	0.0693
Sigma_e	0.2530	0.2678	0.1377	0.1488
Rho	0.2658	0.2290	0.1615	0.1781

Notes: Numbers in parentheses are robust standard errors.
[a]In Treatments 4 and 5, we only include subjects who do not pay to know the probability.
[b]In Treatments 4 and 5, we only include subjects who pay to know the probability.
*Significant at the 10% level; **Significant at the 5% level; ***Significant at the 1% level.

driven by the impact of the endogenous probability of provision on both the private and the public goods. This impact is stronger on the private good, that is, increasing the emphasis on the private good (allowing the probability of provision to increase with contributions), crowds out the incentive to contribute to the public good. The behavior of subjects in Treatment 7 suggests that even though they contribute a little more, they do not fully realize the incentives to contribute when these incentives are public in nature and targeted toward total group contributions.[21] We test the difference in contribution levels more specifically later using Hypothesis 5 (comparing across Treatments 4 and 6) and Hypothesis 6 (comparing across Treatments 5 and 7).

Results associated with Hypotheses 3–6, which examine whether individuals behave differently when they face risk, uncertainty, or can change the probability they face, are presented in Tables 3, 6, and 7. Hypothesis 3, that is, in payoff-equivalent situations, subjects' contribution level to the public good is higher when facing uncertainty than when facing risk, both associated with the private good, is not supported by the tests and the regression results (dummy for Treatment 4 is negative and significant).[22] The negative sign indicates positive optimism or wishful thinking on the part of the subjects. In Treatment 2, subjects know that they have only 50% chance of obtaining the private good. In Treatment 4, subjects face uncertainty on the private good, and in this case, they could put more weight on the high end of the distribution. Subjects seem to interpret uncertainty relating to the private good to justify their lower contribution to the public good. Wishful thinking is discussed in the context of uncertainty in common pool resource experiments (Budescu, Rapoport, and Suleiman 1995a, 1995b; Gustafsson, Biel, and Gärling

21. In the literature, there is little direct comparison of public versus private contributions with endogenous treatments, so it is difficult to compare our results with previous findings. Some work in this area suggests that incentives do not significantly alter contribution levels when benefits are accrued by all group members and are public in nature (Dickinson 1998) but they do when the incentives of contributing are private in nature (Dickinson 2001).

22. For this comparison, we exclude subjects who choose to pay to know the probability (converting uncertainty into risk). Hence, we compare the risk treatment with the data on pure uncertainty from Treatment 4. The dummy for Treatment 4 would be positive and significant if the data supported Hypothesis 3.

TABLE 7
Random Effects GLS Estimates for the Individual Contribution Levels: Pairwise Regressions, Testing Hypotheses 5 and 6

	Treatments 4[a] and 6	Treatments 5[a] and 7
Invperiod	0.3502*** (0.0915)	0.2063*** (0.0661)
Treatment	−0.2833*** (0.0592)	0.0549* (0.0285)
Loutcome	0.0146 (0.0269)	−0.0038 (0.0053)
Ldeviation	0.0040*** (0.0007)	0.0026*** (0.0010)
Sex	0.0500 (0.0510)	0.0024 (0.0476)
Age	0.0106** (0.0041)	0.0035** (0.0017)
Risk_averse	0.0374 (0.0434)	−0.0508 (0.0550)
Risk_neutral	0.0762 (0.0685)	0.1370 (0.0911)
Constant	0.0575 (0.1050)	0.0024 (0.0971)
Observations	1,097	1,329
Sigma_u	0.1018	0.1056
Sigma_e	0.2063	0.1522
Rho	0.1957	0.3251

Notes: Numbers in parentheses are robust standard errors.
[a]In Treatments 4 and 5, we only include subjects who do not pay to know the probabilities.
*Significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

1999; Rapoport et al. 1992; Suleiman, Budescu, and Rapoport 1960) with findings that with an increased level of uncertainty regarding the size of the resource, the resource request from the common pool resource increased.[23] It seems that when subjects estimate the probabilities, they have the tendency to over- or underestimate it depending on what they hope for.[24]

Hypothesis 4, that is, in payoff-equivalent situations, subjects' contribution level to the public good is lower when facing uncertainty than when facing risk, both associated with the public good, is not supported. The dummy for Treatment 5 is negative but not significant, indicating that the contributions to the public good are not significantly different when subjects face uncertainty as compared to risk. The negative sign suggests that subjects are fearful of wasting ones' contribution due to pessimistic beliefs about the environmental uncertainty relating to the public good.[25] This argument is complementary to the wishful thinking relating to the private good. Hence, whether subjects have optimistic or pessimistic beliefs about provision could depend on the location of uncertainty: on the private or the public good. Separating the data for subjects who want to know the probability they face in Treatment 5, we find that for subjects who choose to convert uncertainty into risk, the contributions are higher in Treatment 5.[26]

23. It is difficult to directly compare this literature here, as in our paper, we find indications of optimism when the uncertainty relates to the private good, so it is in the subject's private interest to put more weight on the high end of the distribution. In the literature cited, optimism is discussed in situations when there is uncertainty on a common pool resource and not a private good. The aim of providing these references is to connect the concept of optimism to the literature; however, we should keep in mind that the location of the uncertainty matters.

24. In Table 6, we also present results from regressions where we include only individuals who pay to know the probability in Treatment 4 and compare to behavior in Treatment 2. The dummy for Treatment 4 remains negative and significant for this subsample. It seems as if subjects who pay to know the probability facing the private good have already made a commitment toward the private good and so continue to contribute in that direction.

25. Pessimism has been discussed in the context of public good threshold experiments in Au (2004) and Wit and Wilke (1998), and they find that group members justify their noncooperation by pessimism. Bac (1996) labels a player as pessimistic if the player thinks that he or she is the only player who desires the public good and hence expects that others will not contribute.

26. Note the difference in results for private and public goods here. In Treatment 4 when we only include subjects who have paid to know the probability, we find that subjects contribute significantly less to the public good in Treatment 4. However, subjects contribute significantly more to the public good in Treatment 5 (Column 5 of Table 6). The result in the case of the private good could potentially suggest that there is an order effect in the data (as contributions decline). However, in the case of the public good, the contributions actually increase, not decline. So order effects are perhaps not a convincing explanation for our results. Instead, we suggest that there are other reasons (such as commitment toward the good in question) for this result.

TABLE 8
Random Effects GLS Estimates for the Individual Contribution Levels: Pooled Regressions

Variables	Model 1	Model 2	Model 3
Invperiod	0.226*** (0.0374)	0.369*** (0.0540)	0.369*** (0.030)
T2	0.267*** (0.0550)	0.279*** (0.0573)	0.279*** (0.014)
T3	−0.122*** (0.0264)	−0.108*** (0.0275)	−0.108*** (0.014)
T4	0.204*** (0.0599)	0.211*** (0.0639)	0.211*** (0.014)
T5	−0.143*** (0.0428)	−0.131*** (0.0459)	−0.131*** (0.014)
T6	−0.099* (0.0530)	−0.093* (0.0551)	−0.093*** (0.013)
T7	−0.086*** (0.0396)	−0.081*** (0.0394)	−0.081*** (0.014)
Loutcome		0.017 (0.0147)	0.016** (0.008)
Ldeviation		0.004*** (0.0006)	0.004*** (0.000)
Sex			0.006 (0.029)
Age			0.004 (0.003)
Risk_averse			−0.008 (0.040)
Risk_neutral			0.092 (0.059)
Constant	0.196*** (0.0570)	0.156*** (0.0586)	0.057*** (0.072)
Sigma_u	0.1486	0.0973	0.0980
Sigma_e	0.2685	0.2467	0.2467
Rho	0.2344	0.1347	0.1365

Notes: For the most inclusive model (Model 3): pairwise tests within pooled regressions: Test T2 = T3, $\chi^2(1)$ = 491.76***; Test T4 = T5, $\chi^2(1)$ = 444.49***; Test T6 = T7, $\chi^2(1)$ = 1.84; Test T2 = T4, $\chi^2(1)$ = 14.61***; Test T3 = T5, $\chi^2(1)$ = 10.08***; Test T2 = T6, $\chi^2(1)$ = 543.66***; Test T4 = T6, $\chi^2(1)$ = 392.08***; Test T3 = T7, $\chi^2(1)$ = 0.39; Test T5 = T7, $\chi^2(1)$ = 6.33***. Numbers in parentheses are robust standard errors.

*Significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

These subjects paid a fee to know the probability, so they are perhaps the subjects who would be more aware about contributions to the public good and are already committed toward the public good. This may explain the statistically significant increase in contribution levels relative to Treatment 3.

We obtain strong support for Hypothesis 5. Both the statistical tests (Table 3) and the regressions (Table 7) show that in payoff-equivalent situations, when probabilities are endogenous, that is, subjects can increase the probability of provision of the private good (Treatment 6), subjects' contribution to the public good will be lower than that when facing uncertainty on the private good (Treatment 4). In Treatment 6, subjects can increase the probability of return they face if they invest more in the private good. This incentive crowds out the contribution to the public good.

Hypothesis 6, that is, in payoff-equivalent situations, when probabilities are endogenous (Treatment 7), subjects' contribution to the public good will be higher than when facing uncertainty associated with the public good (Treatment 5), gets some support from the data (Tables 3 and 7). The point estimates show that the contributions are higher in Treatment 7 and statistically significant in the regressions.[27]

C. Other Regressors

The results from the multivariate regressions show that the time variable is positive and highly significant, implying that contributions to the public good decay over time.[28] The variable which measures whether the good was provided in the previous period (loutcome) is positive and significant in some regressions, indicating that a provision of the good in the previous period increases the contribution to the public good in the current period.[29] Deviation (ldeviation) which captures the

27. Dickinson (1998) shows that incentives do not significantly affect contribution levels in public goods games.

28. The specification of this variable captures the nonlinearity in the data. Figure 2 indicates that contributions have a nonlinear pattern with a sharper drop in the early periods and a more gradual decline in the later period for most treatments; hence, this particular specification (1/time) was used to highlight the time element of the contributions.

29. This variable, however, does not have a consistent sign across regressions.

TABLE 9
Summary of Results for the Hypotheses

Hypotheses	Individual Contributions to the Public Good	Comparison	Sign and Significance	t-Test, Wilcoxon Test and Regression Results
H1	$g_2 > g_3$	Private vs. public risk	Correct sign; statistically significant	Supported
	$g_4 > g_5$	Private vs. public uncertainty		
H2	$g_7 > g_6$	Incentives on private vs. public	Correct sign; not significant	Not supported
H3	$g_4 > g_2$	Uncertainty vs. risk on private	Incorrect sign; statistically significant	Not supported
H4	$g_3 > g_5$	Uncertainty vs. risk on public	Correct sign; not significant	Not supported
H5	$g_4 > g_6$	Private uncertainty vs. incentives	Correct sign; statistically significant	Supported
H6	$g_7 > g_5$	Uncertainty vs. incentives on public	Correct sign; statistically significant	Supported[a]

[a]The regressions support this hypothesis. The point estimates for the statistical tests provide support; however, the difference is not statistically significant.

difference between the individual and group contribution in the previous period is very substantial in explaining contributions, with a higher level of deviation leading to significantly higher contributions in this period. This result is intuitively appealing since it suggests that people use feedback from other members of the group when deciding on future contribution levels. The feedback is used by the subjects as information about the strategic uncertainty, and such information seems to guide subjects in their decision. These results are consistent with Dickinson (1998) who also finds that the deviation of a person's contributions in the previous round from the group affects individual contributions. Furthermore, they confirm Festinger's (1954) conjecture that the more uncertain people are in their knowledge about the task, the more likely it is that they will try to reduce their uncertainty via information on how others respond. The variable lprobincr, which captures the impact of the lag of the increase in probability in the provision of the good, shows that as the probability in the previous period increases, the contributions increase in this period. The variable EM is positive and highly significant in explaining contributions.[30] This result corroborates previous findings, for example, Dickinson (1998), 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. Individual-level characteristics like age, gender, and risk behavior of the subject do not provide a consistent pattern of behavior.[31]

IV. CONCLUSIONS

We use laboratory experiments and a standard public goods game to examine the decisions of subjects when facing both strategic and environmental risks and uncertainties. We keep the strategic uncertainty constant throughout the seven treatments examined in this paper and introduce different forms of risk and uncertainty regarding the provision of private and public goods. We find that even in a payoff-equivalent situation, environmental risk and uncertainty associated with both private and public problems act as a significant factor when making decisions, with subjects moving away from the environmental uncertainty or risk. The location of the

30. Several studies (e.g., Isaac, Walker, and Thomas 1987; Kim and Walker 1984) have investigated the importance of marginal incentives (EM) on contribution levels. In the results reported in the paper, we include EM as an explanatory variable in regressions where we only have data on individuals who want to know the probability they face.

31. These individual-specific variables are sometimes significant in the unreported tobit regressions. Risk-averse subjects (74% of our sample) contribute less, and risk-neutral subjects (10% of our sample) contribute significantly more than risk-loving subjects (16% of our sample). It seems that risk-neutral subjects see the underlying payoff equivalence between the treatments, and they also see that regardless of the risk associated with the returns, the underlying problem is a public goods game with Pareto-efficient contribution levels of 100%. Risk-averse subjects, however, divert away from not only the external risk and uncertainty but also the strategic uncertainty associated with contributing to the public goods.

environmental risk or uncertainty matters: subjects move away from the environmental uncertainty in favor of strategic uncertainty when that uncertainty relates to the private good. When environmental uncertainty relates to the public good, subjects face strategic and environmental uncertainty on the same good, leading to a collapse of the contributions.

Our results could be used to understand some aspects of environmental policy making. For example, the climate change negotiations that have been taking place since 1992 involve a large degree of scientific and economic uncertainty. Our results suggest that it was not the strategic uncertainty, per se, but the presence of the environmental uncertainty that has led to the long period of negotiations on climate change.

In the incentives (endogenous probability of provision) treatments, we find that subjects contribute more than they do in the other treatments, that is, an opportunity to reduce the uncertainty relating to the public good increases cooperation (Hypothesis 6). This relates to the role of innovation in determining outcomes. The reward for research and development and innovation is captured here by the increased probability of obtaining the desired outcome in the endogenous probability treatment.

Subjects are willing to pay a fee to reveal the uncertainty in treatments where the uncertainty relates to a private good rather than a public good. Interestingly, we find that some subjects are willing to pay to avoid uncertainty (unknown probabilities) in favor of risk (known probabilities) even if such probabilities play little role in their decision making. We also find that information on fellow group members' cooperation seems to serve as a norm of how to deal with uncertainty. This indicates that transparency of international negotiations could serve as an important factor in the success of the negotiations, since participants use the contributions of other group members as a yardstick when facing strategic and environmental uncertainty.

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