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Voluntary contributions to reduce expected public losses

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Abstract

We examine voluntary private contributions to reduce the probability of a public loss in the experimental economics laboratory. In several treatments, we examine how loss probability, initial wealth and ambiguity affect the contribution level. We observe that, in contrast to the risk-neutral Nash equilibrium, participants do make positive contributions although the contribution level is lower than in the typical experiments on voluntary contributions to fund public goods. Reciprocity plays an important role in individual decision-making. The occurrence of a loss decreases the aggregate contribution level.

JEL classification: H49; D81; C23; C92

Keywords: Voluntary contributions; Collective loss; Risk; Uncertainty; Experimental economics

1. Introduction

Environmental disasters occur with a startling frequency; one need think only of the number of hurricanes and forest fires in the United States, the Tsunami in the Indian Ocean, earthquakes in Pakistan, or floods in Europe during the past years. The mad cow, foot and mouth, and bird flu diseases are other examples of disasters affecting a great number of people in many countries. For a given country in a given year, the probability that such a disaster might occur is far from negligible.

It is recognized in the literature that the consequences of major natural disasters aggregate private prevention problems to a collective loss issue (Kunreuther, 1997; Petak, 1998). Government interventions are typically asked for. Consider, for example, the public funding for firefighters.

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The financial losses associated with a disaster could, however, often be reduced by a voluntary collective effort without government aid. It is, thus, important to know how much of their personal wealth or effort individuals would voluntarily invest into a collective attempt to reduce the expectation of such losses.

An interesting question also is whether the willingness to invest changes after the occurrence of a disaster implying substantial losses. The literature on private disaster insurance observes that uninsured losses decrease the likelihood of insurance purchases (Ganderton et al., 2000.) The rationale for this can be twofold. First, people might think that once a loss has occurred the likelihood of recurrence is very small. Second, people might forego insurance in order to save the premium and regain their losses.

These are the kinds of question that we address in a series of laboratory experiments where voluntary private contributions to a public investment reduce the probability of a big loss affecting everybody in the group. Our experiments are based on the *voluntary contributions mechanism* that has been used to examine the financing of public goods in the experimental economics literature (e.g., Davis and Holt, 1993).

A typical outcome, reproduced in many experiments on repeated public goods games, is substantial contributions to the public good that clearly exceed the contribution predicted by the Nash equilibrium. However, contributions to the public good tend to decrease when the final repetition approaches. Explanations of the observed over-contribution include *altruism* (Andreoni, 1990; Goeree et al., 2002), *warm glow of giving* (Andreoni, 1995), and *conditional or reciprocal behavior* (Sudgen, 1984; Keser and van Winden, 2000; Keser, 2000).

In most public-good experiments, production of the public good is deterministic and continuously depends on the total contribution of the participants. Some authors have relaxed the continuity assumption of the production of the public good and introduced into their experimental studies a minimum contribution required for the production of the public good (e.g., Isaac et al., 1988). In these public-good experiments with a *provision point*, a coordination problem may arise due to the existence of multiple Nash equilibria, implying that a decision-maker faces strategic risk with respect to the others' behavior.

Dickinson (1998) has introduced risk into the production of the public good, suggesting that, although there is no provision point, the public good may not be produced even when there are positive contributions. He considers both a situation where the risk is exogenously determined and a situation where the risk decreases with the contribution level. His results show that the introduction of a production risk has a weakly negative effect on voluntary contributions. Another interesting result is that instances of non-production of the public good in one period have neither a significantly positive nor a negative effect on the contribution level in the next period.

Our experiments differ from those of Dickinson in that contributions decrease the probability of a loss rather than increase the chance of a gain. Following Kahneman and Tversky (1979) and Loomes and Sugden (1986), behavior may differ depending on whether losses or gains are at stake in situations incurring risk.[1] In our loss framework, we address various questions not yet dealt with in the public goods literature.

[1] In riskless public goods experiments, a number of studies find significant differences in the cooperation level depending on whether gains or losses were at stake. Andreoni (1995), for example, finds that contributions are greater when decisions are framed in terms of gains rather than losses. Brown and Stewart (1999) examine the influence of initial wealth on the degree of cooperation in a public bad experiment. They observe no significant difference in the situation where, due to low initial wealth, net losses are at stake compared to the situation where, due to high initial wealth, net gains are at stake.

We examine to what extent collective investments are affected by the ex ante probability of loss and the size of the original wealth. Furthermore, we investigate whether collective contributions increase or decrease after a loss has been experienced. To examine whether information about the loss probability matters, we have, in some of the experimental treatments, participants play under the condition of pure *risk* (with knowledge of the loss probability with and without any voluntary public investment). In other treatments, participants know the amount of the potential loss but have no information about the probability of the loss and its potential reduction through contribution. We refer to this situation as one of *uncertainty* or *ambiguity.* In all of our experimental treatments, if no contribution to the public account is made, the expected loss is the same.

Our results show that the level of voluntary contribution decreases with the risk of a loss and with the introduction of uncertainty about this risk. We observe that the level of voluntary contribution tends to decrease after a loss. Interestingly, this decrease in the overall contribution level comes along with an individual tendency to increase rather than decrease one's contribution level after a loss; the increases however are less important than the less frequent decreases. Furthermore, the probability of playing the Nash dominant strategy of zero contribution significantly increases after a loss.

In the following section we describe the design of our experimental study. In Section 3 we use nonparametric and parametric techniques to analyze our experimental data. Section 4 concludes the article.

2. Experimental design

In this section, we present a game in which voluntary public investments reduce the probability of a public loss. We also discuss the various experimental treatments and relate them to the objectives of our study.

2.1. The game

Let each of n players be endowed with e tokens to be allocated between two alternatives, a private investment X and a public investment Y. Let x_i, $x_i \in \{0, 1, \ldots, e\}$, be the number of tokens that player i invests in X, and let y_i, $y_i \in \{0, 1, \ldots, e\}$, be the number of tokens that he invests in Y. All tokens must be allocated (i.e., $x_i + y_i = e$).

Each token invested by player i in X yields him a private return of r, where $r > 0$. Each token invested in Y reduces the probability of a loss. This loss, if it occurs, affects all n players and amounts to C for each player. The following equation defines the probability, p, that the loss occurs, depending on the group's investment in Y:

$$p = p^* - \left(\sum_{i=1}^{n} y_i\right) \frac{a}{ne}, \tag{1}$$

where p^* is the ex ante probability of the loss if no collective effort is made, that is, if nobody invests in Y, and a ($a > 0$) is a constant. The second term of Eq. (1) shows how the probability of loss declines with the group's contribution to the public investment Y. At the limit, if $\sum_{i=1}^{n} y_i = ne$, then $p = p^* - a$. Thus, the constant a determines by how much the probability of the loss decreases if all players allocate their entire endowment to Y.

Assuming risk neutrality of all players allows us to consider for each player i ($i = 1, \ldots, n$) the following expected individual payoff, Π_i, of this game:

$$\Pi_i = rx_i - \left[p^* - \left(y_i + \sum_{j\neq i} y_j\right)\frac{a}{ne}\right]C. \tag{2}$$

Under the assumption of risk neutrality, the typical public-good conditions are satisfied if the following two parameter conditions are satisfied at the same time:

(1) If $r > Ca/ne$, the return of a token allocated to the private investment X exceeds the expected loss reduction associated with placing the same token into the public investment Y. This implies that the dominant strategy for each individual is to invest nothing in Y. In other words, economic theory predicts free-riding behavior for all players.
(2) If $Ca/e > r$, the collective return of each token invested in Y is greater than the individual return of the same token invested in X. The collective optimum is thus realized if all players invest all of their tokens in Y.

If we abandon the assumption of risk neutrality, we have to consider the expected utility function U_i of player i:

$$\begin{aligned} U_i = &\left[p^* - \left(ne - x_i - \sum_{j\neq i} x_j\right)\frac{a}{ne}\right] u_i(rx_i - C) \\ &+ \left[1 - \left(p^* - \left(ne - x_i - \sum_{j\neq i} x_j\right)\frac{a}{ne}\right)\right] u_i(rx_i), \end{aligned} \tag{3}$$

where $u_i(\cdot)$ is player i's individual utility function. For a risk-averse player we have $u_i'(\cdot) > 0$ and $u_i''(\cdot) < 0$.

Maximization of player i's expected utility function with respect to x_i and taking the others' contribution, $\sum_{j\neq i} x_j$, as given leads to a best reply function that depends on the others' contribution. Thus, zero contribution to the public investment is no longer a dominant strategy, and positive contributions can form a Nash equilibrium. However, to determine the Nash equilibrium, we need to specify the utility function for each of the n players in an ad hoc way.

These solutions are based on the assumption of the players' common knowledge about the probability of the loss. If we abandon this assumption and allow for ambiguity about the probability, we can expect multiple Bayesian equilibria. A formal model of this type is outside the scope of the present paper.

2.2. Experimental treatments

We consider five different treatments, in all of which we keep the expected loss in the absence of investment in Y constant. More specifically, with ex ante loss probabilities, p^*, set equal to either 20 or 40%, and the corresponding losses, C, at 1000 or 500, respectively, the expected loss without investment in Y equals 200 in each treatment. Furthermore, for each token invested in Y, we assume that the reduction in the expected loss is the same in all cases. With three players, $n = 3$, and an endowment of 10 tokens, $e = 10$, in all treatments, the parameter a in Eq. (1) defining

Table 1
Experimental treatments

Treatment	Initial probability, p^* (%)	Loss, C	Initial endowment, W	Ambiguity
R20-7500	20	1000	7,500	No
A20-7500	20	1000	7,500	Yes
R40-7500	40	500	7,500	No
R40-15,000	40	500	15,000	No
A40-15,000	40	500	15,000	Yes

Note: The treatments are identified by the letter R or A, designating experiments conducted under risk or ambiguity, respectively. This first letter is followed by the probability of loss and the initial wealth.

the endogenous loss probability is chosen to ensure that this condition is maintained: $a = 0.15$ when $p^* = 20\%$ and $C = 1000$, and $a = 0.30$ when $p^* = 40\%$ and $C = 500$. Thus, the reduction in expected loss per token is $aC/(ne) = 5$ in all treatments. Keeping the private return per token invested in X at $r = 10$, the expected marginal rate of substitution of the private for the public investment, under the assumption of risk neutrality, is equal to one half in all treatments.[2] The participants begin the experiment with an initial wealth (account balance), W, equal to 7500 or 15,000. Note that in the treatments where the initial wealth is 7500, the expected concluding wealth after 100 periods is negative if no tokens are invested in Y.

In some of the treatments, the participants play under conditions of *ambiguity*, that is, knowing neither the probability of loss if no tokens are invested in Y nor the reduction in loss probability associated with each invested token. They are, however, informed of the size of the potential loss. In the treatments with *risk*, the players have complete information of the size of the potential loss, the probability of loss if no tokens are invested in Y, and the reduction in loss probability associated with each invested token. Table 1 gives an overview of the treatment design.

In each of the five treatments, we have eight independent groups of three participants. Therefore, we have 24 participants per treatment for a total of 120 participants. The game is repeated over 100 periods with the (anonymous) membership of the group unchanged over time.

In the risk treatments, assuming risk neutrality, the unique subgame perfect equilibrium is obtained by backward induction: it consists of making no investments in Y in each of the 100 repetitions. The social optimum is to invest everything in Y in each repetition.

If we assume that participants are risk averse, we are to deal with insurance issues in addition to the public-good problem. However, because we consider a collective loss rather than a private-insurance problem, the public-good dimension of the problem remains dominant.

Assuming for each of the participants a *Constant Absolute Risk Aversion* (CARA) utility function of the type ($u_i = -\exp(-\gamma\omega_i)$, with ω_i denoting player i's wealth and with $\gamma > 0$), we can show, using our experimental parameters, that interior solutions to the Nash equilibrium exist over a small range of very low values for the risk aversion parameter γ. Over that small range, contributions to Y are increasing with γ. Risk-aversion parameters below the lower bound yield the solution of the risk-neutral assumption, no investments in Y. Above the upper bound, which in our case is still a low risk-aversion parameter, the Nash solution is to invest everything in Y. The CARA utility function is relatively well suited for our problem, as the utility is considered to vary with wealth and remains defined for any gains and losses.

[2] This marginal rate of substitution for a riskless public good has been described by Ledyard (1995). Isaac et al. (1984) call it the marginal per capita return (MPCR). In our model, the expected marginal rate of substitution of the private investment for the public investment is: $(\partial\Pi_i/\partial y_i)/(\partial\Pi_i/\partial x_i) = (aC/ne)/r$.

In the treatments with ambiguity, among the multiple Bayesian equilibria, zero contribution to *Y* predicted by the subgame perfect equilibrium under risk neutrality or by very low risk aversion in the risk treatments (no ambiguity) may be considered a benchmark solution.

We conducted the experiments in the experimental economics laboratory LUB-C3E at the *Centre Interuniversitaire de Recherche en ANalyse des Organisations* (CIRANO). Participants were from several Montreal universities. After reading the instructions (in French, an English translation is available in Appendix) they had to go through an online questionnaire before an experiment began.

Participants were paid based on their concluding account balance in the experiment with a known conversion rate of 1 Canadian dollar per 400 points. In the rare case that a participant ended up with a negative or a very low final account balance, we paid a minimum of 10 Canadian dollars.[3] On average, participants earned 21 Canadian dollars for about 1 h of effort.

2.3. Objectives

The focus of our analysis is on the following three questions:

- *First*, *we examine how the loss probability affects the contribution level*. More concretely, we compare contribution levels in situations with a relatively small probability of a potential loss (R20-7500) to a situation with a large probability of a potential loss (R40-7500). In the literature we find divergent observations with respect to very small probabilities. Kahneman and Tversky observe that individuals overestimate small probabilities in lotteries. Other authors (Camerer and Kunreuther, 1989a) find that small probabilities are ignored. In our experiments, the former would imply that participants contribute more with a small than with a large loss probability, and the latter would imply that participants contribute less with a small than with a large loss probability. Although 20% is not a very small probability, it is small relative to 40%.[4] We thus hypothesize that the contribution level is affected by the probability of a loss.
- *The second focus of our analysis is on whether people respond differently to ambiguity than to risk*. Comparison of the results of experiments R20-7500 and A20-7500 and those of R40-15,000 and A40-15,000 reveal whether participants respond with less collective effort to ambiguity than to risk. In Cohen et al. (1987), this is referred to as pessimism or ambiguity aversion. Camerer and Kunreuther (1989b) observe in an experimental insurance market that prices are not affected by ambiguity about the probability of a loss.
- *Third*, *we investigate how individuals behave subsequent to a loss*. Intuitively, one might expect a greater collective effort after a loss. The event of a loss provides the occasion for a reassessment of each participant's strategy, and one might expect a natural disaster to galvanize efforts geared at prevention. This corresponds to the availability hypothesis that a recent loss is predominant in memory and, thus, temporarily increases the subjective probability of a current loss (Tversky and Kahneman, 1973). However, individuals might have

[3] In the literature, there are only a few experiments where participants could experience real losses (e.g., Cohen et al., 1987).

[4] To generate several losses with extremely small probabilities in the laboratory we would need to have our participants play a very large number (thousands) of periods. This would impose logistic problems and, in particular, participants would likely become bored or tired of the game.

the opposite reaction, supposing that such an event is not likely to recur soon. This obviously implies an erroneous belief in conditional probabilities, a form of *gambler's fallacy* as in Camerer and Kunreuther (1989b). The same reaction might result if individuals attempt to regain a previous loss. This is known as a reference-dependence effect (Tversky and Kahneman, 1991).

The five experimental treatments also allow us to address several questions associated with the traditional voluntary contributions and disaster-insurance issues. Among those are reciprocity and wealth effects.

3. Experimental results

In the first part of this section, we provide a descriptive analysis of our experimental data. We also present non-parametric statistics, based on SPSS 10.0. All tests are two-sided. We denote the Mann–Whitney *U*-test simply as the *U*-test, and the Wilcoxon signed rank test as the Wilcoxon test. The second part of this section presents results based on regression analyses.

3.1. Descriptive analysis

Table 2 summarizes some descriptive results on voluntary contributions observed across the five experimental treatments. Considering the mean and median of the contributions, it is obvious that the dominant strategy of zero contribution under risk neutrality does, on the aggregate, not explain the participants' behavior. At the same time, the observed average contributions in all five treatments are far below the efficient level of the full contribution of all 10 tokens. The average contributions in the various treatments, divided by the group optimum of full contribution, yield efficiency levels varying between 22 and 32%. These are below the typical efficiency levels between 40 and 60% in traditional public-goods experiments, where the public good represents a tangible payoff for each group member (Ledyard, 1995; Ostrom, 2000). The results are consistent with an interior solution assuming risk-averse participants.

We observe that the contribution level is higher in R20-7500 than in A20-7500 and higher in R40-15,000 than in A40-15,000. This suggests a negative impact of ambiguity on the contribution level. We also observe a higher contribution level in R20-7500 than in R40-7500. This is in keeping with the interpretation of an overestimation of small probabilities. Furthermore, the contribution level is higher in R40-1500 than in R40-7500, which suggests a positive effect of initial wealth on the contribution level. However, these effects are statistically not significant when we use very

Table 2
Statistics on voluntary contributions (by treatment)

Treatment	Mean	Median	Mean standard deviation in groups	Mean first period	Median first period	Mean period, 1–50	Mean period, 50–100
R20-7500	3.25	3	2.08	5.25	5	3.23	3.27
A20-7500	2.22	2	1.91	4.29	5	2.38	2.05
R40-7500	2.57	2	2.47	4.17	4	2.82	2.32
R40-15,000	3.02	3	2.68	3.92	5	3.29	2.75
A40-15,000	2.88	3	2.63	4.13	4.5	3.19	2.57

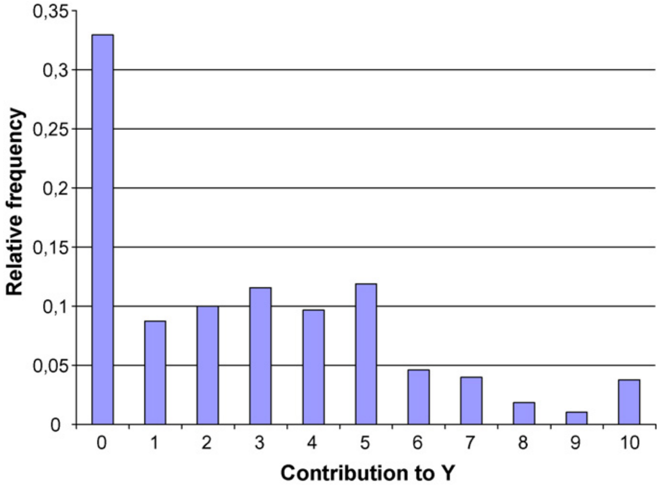

Fig. 1. Distribution of contributions to *Y* (over all treatments).

conservative *U*-tests based on the average contribution levels of the independent groups (10% significance). [5]

The contributions to the public investment during the first period tend to determine the long-run contribution level in a group: pooling our data over all five treatments, the Spearman rank correlation coefficient shows a significantly positive correlation of 0.307 between the first-period contribution and the average contribution over all following periods in the group (10% significance level).[6] Since the first-period contributions do not significantly differ across treatments (*U*-tests, 10% significance), it is not surprising that the overall contribution levels do not significantly differ.

The contribution level to the public investment shows a tendency to decline over time. Comparing the mean voluntary contributions in the first 50 periods with those in the last 50, we observe a statistically significant decline if we pool the observations of all treatments (sign test, 5% significance level, Wilcoxon test, 1% significance level).

Fig. 1 presents the distribution of individual contributions of all subjects in all treatments and all periods. There is a single mode at a contribution of zero token with an observed frequency of 32.92%. Contributions of six or more tokens occur only rarely. The frequency of full contribution (10 tokens) is as low as 3.77%. This is in contrast to many riskless public-goods experiments where a bimodal distribution is observed, with modes at zero and full contribution.

We know from previous public-goods experiments that subjects adjust their contributions to the others' average contribution in the previous period. In Keser and van Winden (p. 33) this kind of *reciprocity* is defined in a qualitative way: *if a subject changes his contribution from one*

[5] Considering the average standard deviation of contributions in the groups, we do not observe a significant influence of ambiguity or of the probability of a loss or of initial wealth (*U*-tests based on the standard deviations of the independent groups, 10% significance). We observe, however, a significant joint wealth-probability effect on the standard deviation. The standard deviation is larger in R40-15,000 than in R20-7500 (*U*-test, 10% significance level). It is also larger in A40-1500 than in A20-7500, but the *U*-test just fails significance ($p = 0.1036$). In other words, the larger the initial wealth and the probability of a loss, the higher the standard deviation.

[6] Keser and van Winden (2000) and Fehr and Gächter (2000) made similar observations.

period to the next, he adjusts it toward the previous group average. In other words, he increases his contribution if it was below the group average in the previous period and decreases it if it was above. Given this definition, we observe in each individual group that subjects, if they change their contributions, react in a reciprocal way in the majority of cases. Thus, reciprocity plays a significant role in our experiments (binomial test, 1% significance level overall, 2% significance level for each treatment).

Examining reciprocity separately for the cases of a loss or no loss in the previous period, we observe that in the no-loss case again all 40 groups react in the majority of instances in the predicted way. However, in the loss case only 28 of the 40 groups react in the majority of instances in the predicted way. However, reciprocity is still significant at the 2% level (binomial test).

In the period after a loss, we observe that in 23 groups the majority of members tend to increase rather than decrease their contributions, while in 13 groups the opposite is true. We may conclude that, over all treatments, there is a tendency to increase rather than decrease one's contribution in the period after a loss has occurred. This would support the availability hypothesis (a recent loss is more available in memory) rather than the gambler's fallacy hypothesis. However, this tendency fails statistical significance (sign test, 10% significance).

Similarly, in the period after a loss, the group contribution to the public investment increases in the majority of cases in 25 groups, and it decreases in 14 groups. The higher frequency of an increase rather than a decrease in the group contribution level just fails statistical significance (sign test, $p = 0.109$). This increase supports the availability hypothesis (a recent loss is more available in memory) rather than the gambler's fallacy hypothesis. Interestingly, however, although increases occur more frequently than decreases, the average decrease in the group contribution level over all groups of −4.90 is more important than the average increase of 4.60.

3.2. Regression analysis

In our experiments, interdependence between the members of a group is a key feature, but because the groups are assembled randomly and their membership is anonymous, voluntary contributions to the public investment, Y, by other members of a given group in the previous period explicitly account for the interaction between group members. To explain individual data, we condition our regressions on this variable to resolve the endogeneity problem associated with the interactions.[7]

Our experimental data set consists of panel data. Each participant plays 100 times. In the panel regressions, we introduce an individual effect that among others can be interpreted as an idiosyncratic attitude of the participants toward risk (see Hoffman et al., 1998). Unfortunately, this does not give us a measure of risk aversion and a way to discriminate among the theoretical benchmarks presented in Section 2.1. Furthermore, to the extent that individual effects are significant, it indicates a problem of heterogeneity among participants. The econometric analysis accounts for different behaviors among participants, whereas heterogeneity is not allowed for in the theoretical models, which assume symmetrical individual decisions and the same risk attitude for all. This suggests that an econometric structural model based on the theoretical benchmarks of Section 2.1 imposes objectionable constraints to the data. We avoid this difficulty with a reduced form model at the cost, however, of not being able to discriminate among alternative explanations of the results.

[7] For a very thoughtful discussion on the issue of identification in experiments, see Manski (2002).

Table 3
Variables of the econometric models

Symbol	Definition
Endogenous	
Nash	1 if zero contribution; 0 otherwise
Voluntary contributions	Number of tokens invested in *Y* by each participant
Exogenous	
Male	1 if the player is male; 0 otherwise
Dummy for first period	1 in period one of the game; 0 otherwise
Dummy for last five periods	1 in the last 5 periods of the game; 0 otherwise
Others' contribution in preceding period	Number of tokens invested in *Y* by the other group members in the preceding period
Interaction: male and others' contribution	Crossed-effect between male and other members' contributions in the preceding period
Occurrence of a loss	1 if a loss occurred in the preceding period; 0 otherwise
Negative wealth	A negative value of wealth in the preceding period; 0 otherwise
Positive wealth	A positive value of wealth in the preceding period; 0 otherwise

We consider two econometric models. The *first model* relates to the *Nash equilibrium*, which predicts zero contribution to the public investment *Y* under the risk-neutrality assumption and for a very small risk-aversion parameter. We use a probit model with random effects to explain the determinants of participants playing this strategy. There are, unfortunately, too few observations at the level of 10 to run a random effects probit model to test the choice of the Pareto optimal strategy or the Nash equilibrium under the assumption of sufficiently risk-averse participants.

The *second econometric model* explains the *level of voluntary contributions*, taking into account that it is a non-negative integer with the value zero often observed. We consider tokens invested in *Y* as count data. Unlike in the Nash model, the explained variable (the number of tokens invested in *Y*) is not latent. We seek to understand the determinants of these voluntary contributions by using the negative binomial model with random effects. This model is compatible with the assumption of risk-averse participants.[8,9,10]

In Table 3, we present the variables used in the econometric analysis. *Male* is a gender variable. *Dummy for first period* accounts for first-period effects. *Dummy for last five periods* accounts for end-game effects. *Others' contribution in preceding period* is our reciprocity variable. A positive estimated coefficient of this variable in the contribution model and a negative estimated coefficient in the Nash model suggest that participants tend to reciprocate the contribution of the other group members.[11] The coefficient of the cross-effect variable *interaction: male and others' contribution*

[8] We analyzed another econometric model that is compatible with the assumption of risk-averse participants. It considers the number of tokens invested in *Y* to be an ordinal measure of the participant's intensity of preference for cooperation. It corresponds to an ordered probit model and yielded results similar to those reported below.

[9] An alternative model to explain the probability of not contributing to *Y* or the voluntary contribution level is a panel generalized Tobit. This would assume a continuous dependent variable, which is clearly not the case in our experimental data.

[10] The standard assumption in count data models (Cameron and Trivedi, 1998) is that the probability of high counts gradually diminishes, becoming infinitesimal. Although, theoretically, our data are truncated at the maximum number of 10 tokens, the observed frequency of choosing a specific contribution level decreases from 32.92% of zero contribution to 3.77% of full contribution. In the context of panel data, this truncation issue is a complex question.

[11] Other authors, such as Dickinson, use the difference between individual *i*'s contribution and the mean of the other group members' contribution to account for reciprocity. One difficulty with that approach in a parametric framework is

Table 4
Panel estimates for Nash equilibrium and level of voluntary contributions (pooled data)

	Nash equilibrium	Level of voluntary contribution
Constant	−0.841* (0.076)	2.699* (0.031)
Dummy for first period	−0.899* (0.151)	0.659* (0.063)
Dummy for last five periods	0.268* (0.042)	−0.092* (0.023)
Male	0.541* (0.054)	−1.076* (0.02)
Others' contribution in *t* preceding period	−0.051* (0.004)	0.028* (0.001)
Interaction: others' contribution and male	0.015* (0.005)	0.009* (0.002)
Occurrence of a loss	0.333* (0.024)	−0.098* (0.012)
Negative wealth	−0.118* (0.014)	0.118* (0.007)
Positive wealth	−0.073* (0.003)	0.032* (0.002)
A20-7500	0.034 (0.067)	−1.064* (0.027)
R40-7500	0.699* (0.07)	−1.855* (0.028)
R40-15,000	1.177* (0.077)	−2.262* (0.027)
A40-15,000	0.906* (0.072)	−1.977* (0.027)
ρ	0.405* (0.015)	
a		1.849* (0.339)
b		1.552* (0.195)
$\log L$	−5483.86	−23685.30

Numbers in parentheses are estimated standard errors. *Significant at 1% level. ρ is the incidental parameter for the random effects probit model; a, b are incidental parameters for the negative binomial model with random effects.

measures differences in reciprocity between men and women. The variable *occurrence of a loss* in the previous period permits assessment of the participants' reaction in their collective effort after a disaster.

We also consider two variables associated with wealth. The net balance at the end of the preceding period fluctuates and is generally positive, but it is important to bear in mind that it can be negative. It did indeed fall below zero in the two treatments with an initial endowment of 7500 (A20-7500 and R40-7500). Therefore, we constructed a variable representing the negative segment of wealth, *Negative Wealth*, and another variable, *Positive wealth*, representing the positive segment of wealth.

Table 4 presents the results of the regression analyses of the two models, each based on the pooled data over all five treatments. We differentiate the treatment effects on the probability of playing the Nash strategy of zero contribution and on the level of voluntary contributions by the use of dummy variables.[12] The pooling relies on two assumptions: (1) that the slopes of the explanatory variables do not vary significantly between treatments, and (2) that we can ignore the issue of variations in (unobserved) heterogeneity across treatments.

3.2.1. Probability to play Nash equilibrium

Assuming risk neutrality, the first set of results reports the determinants of the probability of participants playing the Nash equilibrium dominant strategy. The coefficients of the treatment dummies are evaluated relative to R20-7500, the risk treatment with a low loss probability and a low initial wealth. *Ceteris paribus*, the probability of playing the Nash strategy increases with

the endogenous nature of a deviation variable. It includes the lagged dependent variable and may thus be correlated in a panel model due to the presence of an individual effect. This issue becomes even more complicated in the nonlinear models that we use.

[12] We consider the R20-7500 treatment as the baseline and include dummy variables for all other treatments.

the loss probability in the risk treatment (R40-7500 relative to the reference treatment). Also a higher initial wealth with the same high risk of loss (R40-15,000 versus R40-7500) increases this probability.[13] In treatment A20-7500 that has the same probability of loss and initial wealth as the reference treatment but ambiguity rather than pure risk, we observe a small but statistically insignificant increase in the probability of playing Nash. The increase is substantial and statistically significant in the ambiguity treatment with a higher probability of loss and a higher initial wealth (A40-15,000). Because there is no statistically significant difference between A40-15,000 and R40-15,000, ambiguity per se does not affect the probability of playing the Nash strategy.

We observe a *first-period effect* decreasing the probability of playing the Nash strategy, which could be due to optimism, confusion, or a signal of potential interest in cooperation. An end-game effect increases this probability. There is a gender effect, with the male participants being more likely to play Nash than the female participants. We observe a reciprocity effect: the greater the voluntary contribution of other group members to *Y*, the less the participant will be inclined to play the Nash strategy during the following period. This reciprocity effect is less important for men than for women. All of these results are typical for public goods experiments.

In the period after the occurrence of a loss, the probability of playing Nash significantly increases. The coefficient of this variable is 0.333 and thus more important than the estimated coefficient of 0.268 for the end-game effect. This suggests a gambler's fallacy effect or reference dependence with individuals attempting to regain a previous loss.

The estimated coefficients for the wealth variables show that an increase in the positive balance reduces the probability of adopting a Nash strategy, while a more negative balance increases it. This result is in some respect consistent with Kahneman and Tversky's prospect theory, which says that people tend to be risk seeking when they face a potential loss and risk averse when they face a potential gain. In our game, if we ignore the *strategic risk* of the players' interaction and exclusively consider the *risk of a loss*, we have shown that, under the assumption of a CARA utility function, being sufficiently risk averse implies contribution to *Y*, where, within a specific range, the contribution level increases with the degree of risk aversion. Being risk neutral or having sufficiently little risk aversion implies zero contribution to *Y*. Thus, the observation that a more positive wealth decreases the probability of contributing nothing to *Y* can be interpreted as being due to a higher degree of risk aversion, and vice versa.

Note that if participants have a CARA utility function with a very low level of risk aversion, zero contribution to *Y* by each of the group members is a simple Nash equilibrium. It is no longer a dominant strategy, though. Thus, in this context, the regression presents only a conditional test of the Nash equilibrium strategy, assuming that everybody else plays the Nash equilibrium.

Note also that our theoretical benchmarks suppose homogenous participants in their attitude toward risk and symmetrical behavior. However, the statistically significant ρ coefficient presented in Table 4 validates the random effects probit model, which questions the assumption of homogeneous risk attitudes.

3.2.2. Voluntary contribution level

The second set of results represents the level of voluntary contributions model under the assumption of risk neutrality. We expect the signs of the estimated coefficients to be opposite to their counterparts in the Nash model. Variables that have the effect of increasing (decreasing) the probability of the Nash strategy should decrease (increase) the level of voluntary contributions.

[13] The difference is statistically significant at the 1% level using a simple *t*-test.

This is what we observe in our regressions with one exception, the interaction variable of male and others' contribution.

As noted earlier, with respect to the theoretical analysis this regression model appears better justified in the context of risk-averse individuals. However, our theoretical benchmarks are again questionable in light of the fact that we find statistically significant estimates of the incidental parameters, *a* and *b,* that indicate the pertinence of the random effects specification. The contribution model offers a better comparison with the nonparametric analysis than the Nash model because the level of voluntary contributions is not a latent variable.

For the contribution model, with respect to the reference treatment R20-7500, the coefficients of the treatment dummy variables are negative and statistically significant. This indicates lower contributions, which is consistent with the results presented in Table 2. The results support that voluntary contributions significantly decrease with the probability of a loss. In the cases of a higher loss probability, the contributions also decrease with initial wealth. This suggests that participants are less risk averse the higher their initial wealth.[14] For the same low probability of a loss and initial wealth as in the baseline risk treatment, the voluntary contributions decrease with the introduction of ambiguity. However, the contributions marginally increase (less than 0.30 units) with the introduction of ambiguity if both the probability of a loss and initial wealth are high.[15] Finally, as in Table 2, we observe for the ambiguity treatments a decrease in voluntary contributions with an increase in the probability of a loss and in initial wealth.[16]

The estimated coefficient of the occurrence of a loss variable indicates a weak but statistically significant reduction in voluntary contribution subsequent to the occurrence of a loss. Thus, it corroborates the nonparametric result, where individuals tend to increase rather than decrease their contributions following a loss. It is in keeping, though, with the observation that on average the decrease in units of contribution is more important than the increase. It is also coherent with the strong effect that this variable has in the explanation of zero contributions, as seen earlier.

In an additional regression analysis based on individual behavior per treatment, we relax the assumption of equal slopes for the explanatory variables across treatments. The results suggest some differences in behavior across treatments (not reported here, but available upon request). For example, a first period effect, likely to signal a willingness to cooperate, is present in most treatments but not when the probability of loss is 40%. An end-game effect is particularly important in treatments involving ambiguity, but reciprocity is less apparent in those situations. The observed effects of wealth losses and gains (introducing nonlinear specifications) are not always quantitatively and/or qualitatively similar across treatments. However, we observe robust results concerning the occurrence of a loss variable: a loss significantly and substantially increases the probability of playing the Nash dominant strategy in all treatments. It also weakly reduces the level of voluntary contributions in the subsequent period, but the coefficient estimates are not significant in two treatments involving small probability of a loss and small wealth endowment (R20-7500 and A20-7500).

In short, disaggregating the level of analysis reveals that individual decisions are heterogeneous and contextual. One must therefore be careful to generalize policy recommendations.

[14] The difference in the coefficient estimates of R40-15,000 and R40-7500 is statistically significant at the 1% level using a simple *t*-test.

[15] The difference is statistically different at the 1% level using a simple *t*-test. Note that this specific result differs from the one presented in Table 2.

[16] The difference between the coefficient estimates of A40-7500 and A40-15,000 is statistically different at the 1% level using a simple *t*-test.

4. Conclusion

In this study we have examined behavior relating to voluntary contributions to reduce expected losses associated, for example, with the occurrence of natural disasters. Except for a lower efficiency level and a unimodal distribution of contributions to the public investments, our results are reasonably consistent with those on voluntary contributions to finance a tangible public good. In particular, the Nash equilibrium, under the assumption of risk neutrality, cannot be construed as representative of typical behavior. A similar remark about the validity of our theoretical benchmarks assuming risk adverse participants is justified because the homogeneity assumption concerning the parameter of risk aversion is questionable, as shown with the results of our panel data individual effect estimates. We also observe that reciprocity is an important concept to explain individual behavior.

Both increasing loss probability and introducing ambiguity reduce the level of voluntary contributions, and both increasing loss probability and increasing initial wealth increase the probability of playing risk-neutral Nash. The occurrence of a loss increases the probability of zero contribution to Y at the individual level and decreases voluntary contributions at the group level, although more individuals show a tendency to increase rather than decrease their contributions. Thus, after a natural disaster, the prospect of mobilizing the population to invest in the reduction of expected losses seems quite challenging.

This is just a first step into the investigation of disaster prevention. More research will be needed. Our experiments just consider the potential reduction of the probability of a loss; another opportunity would be to reduce the amount of the loss should it occur. Another shortcoming of our study, similar to most studies on voluntary contributions to a public good, is that we assume symmetry among all players.

Because our results are very much in keeping with those of public-good experiments, we hope to be able to make use of the insights we have gained from the latter to give policy advice on how to motivate people to make voluntary private contributions to future disaster prevention.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jebo.2006.06.007.

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