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# **Externalities in appropriation: Responses to probabilistic losses**

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**Abstract:** We examine behavior in one-shot appropriation games with deterministic and probabilistic degradation externalities, where the marginal net benefit from appropriation is endogenous, dependent on individuals' expectations of group appropriation. The experimental design involves a menu of games where the magnitude of a loss parameter associated with probabilistic degradation varies across games. On average, as the loss parameter increases we observe a significant reduction in group appropriation. There is, however, considerable heterogeneity in behavior. First, subjects who are more pessimistic (optimistic) about group appropriation significantly increase (decrease) appropriation as the loss parameter increases. Second, relative to subjects with more optimistic expectations regarding group appropriation, the appropriation of subjects who are more pessimistic is more closely tied to changes in expected marginal benefits.

**Keywords:** Social dilemma; Laboratory experiment; Endogenous externality; Strategic uncertainty.

**JEL Classification:** D70; D81; H41; C90

# 1 Introduction

A growing number of experimental studies focus on issues related to probabilistic losses associated with the maintenance or provision of public goods. Motivated by issues of climate change, several previous studies have examined the behavioral response to variations in exogenous probabilities of group losses (Milinski et al, 2008; Milinski et al. 2011, Barrett and Dannenberg 2012; Waichman et al 2014). Other contributions, more relevant to this study, examine *endogenous* probabilistic losses. Dickinson (1998) and Gangadharan and Nemes (2009) examine provision-point public goods settings where the probability of provision of a public good increases in contribution levels. In addition, Walker and Gardner (1992) and Blanco et al (forthcoming, BLW thereafter) explore the relevance of endogenous probabilistic losses in appropriation environments. Walker and Gardner (1992) introduce an endogenous probability that a repeated play common-pool resource game ends, where the probability of ending the game increases in total group appropriation. BLW compare settings with and without endogenous probabilities in a one-shot game setting, focusing on the responses to variations in the private benefits from appropriation.

An important example of the relevance of endogenous probabilistic losses in appropriation environments relates to the conservation of natural resources. Conservation can be understood as the provision or maintenance of public goods through the ecosystem services created by the resource.<sup>1</sup> In this context, appropriation

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<sup>1</sup> Substantial research efforts are currently being undertaken to quantify the economic relevance of such ecosystem services. See, for example, Costanza et al. (1997), The Economics of Ecosystems and Biodiversity global initiative (<http://www.teebweb.org/>); the UK National Ecosystem Assessment (<http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx>); the Millennium Ecosystem Assessment (<http://www.unep.org/maweb/en/Responses.aspx>); or the Ecosystem Services for Poverty Alleviation (<http://www.espa.ac.uk/>).

from natural resources generates negative externalities that reduce the quality of ecosystem services, referred to here as degradation externalities. Importantly, appropriation from natural resources can (endogenously) lead to probabilistic losses of ecosystem services beyond the day-to-day deterministic degradation associated with appropriation. These are relevant in a wide collection of settings (see TEEB, 2010) where increasing pressure by resource users results in an increased likelihood that a major ecosystem disturbance occurs and compromises the capacity of the ecosystem to generate ecosystem services or even to survive.

This study contributes to the previous experimental literature by focusing on the role of expected marginal incentives in subjects' individual responses to variations in probabilistic losses. The Deterministic and Probabilistic Degradation (DPD) game studied captures the essence of probabilistic degradation externalities, while abstracting away from production externalities normally associated with appropriation in common-pool resource settings.<sup>2,3</sup> In the games examined, appropriation leads to (i) deterministic degradation, by reducing the value of a shared group resource by a commonly known amount, and to (ii) endogenous probabilistic degradation, where greater appropriation increases the probability that the shared resource faces a loss in

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<sup>2</sup> Extensive field and experimental research has focused on efficiency in use of common-pool resources (CPRs), in particular *production externalities*, whereby appropriation by one user reduces the value of appropriation effort (rent dissipation) by other users (e.g. Agrawal, 2001; Baland and Platteau, 1996; Ostrom 1990; Ostrom et al. 1992, 1994; Wade 1988). Production externalities are generally viewed as situations where appropriation increases the cost per unit of appropriation or increases the effort required per unit appropriated for all users. By focusing primarily on production externalities, this literature has largely neglected the relevance of ecosystem services provided by the natural resources from which appropriation occurs.

<sup>3</sup> The decision situation in this game can be viewed as one in which units of the resource are subtractable in consumption and at the same time the resource itself has the properties of a public good that yields positive value to users, such as varied types of ecosystem services. Earlier studies by Andreoni (1995) and Sonnemans et al. (1998) address decision environments in which subjects' decisions are framed in the context of negative externalities, or preventing a public bad. Also Dufwenberg et al. (2011), address the comparison between behavior in "GIVE frame" and "TAKE frame" games. Cox, et al. (2013) includes a discussion for why the appropriation game studied in this paper is payoff isomorphic to a provision game with the same payoffs. The goal of this study is not to address the role of the different frames in the two games.

value. The magnitude of a loss parameter varies across treatment conditions, including a low, a medium and a high value. From a behavioral perspective, the presence of endogenous probabilistic losses leads to marginal incentives to appropriate that increase with the expected magnitude of group appropriation. The higher a subject's first order beliefs of group appropriation, the higher her perceived incentives to appropriate. For control purposes, the experimental design also includes a "benchmark game" with only deterministic degradation.

The experimental design allows for estimation of the effect of expected marginal incentives on subjects' decisions. A primary issue of interest in understanding responses to probabilistic degradation is to what extent individual changes in behavior can be associated with changes in the perceived marginal incentives to appropriate. Examining this issue entails exploring subjects' behavior in settings where individuals facing the same game parameters perceive heterogeneous marginal benefits from appropriation based on heterogeneous beliefs of others' behavior. Importantly, this study abstracts from group dynamics related to strategic play across decision rounds, as it is based on one-shot decisions in a menu game setting. This menu design is similar to that used in several other studies such as Brandts and Schram (2001), who advocate the use of this method as a mechanism to create a rich data set related to individual decision making. Moreover, decisions in the benchmark game provide a measure of subjects' "baseline cooperation" in a setting where marginal incentives to appropriate are fixed and exogenously imposed by the experimenter.

The results provide evidence that, across games, subjects' appropriation decisions are dependent upon expectations of others' appropriation and the associated net benefits from appropriation. In particular, we provide evidence that subjects'



response to the inclusion of probabilistic losses is strongly correlated with whether their forecasts of group appropriation are above or below a critical appropriation threshold that is derived from the game payoff functions. Those with expectations of group appropriation above the threshold increase appropriation as the magnitude of probabilistic degradation increases across games, while those with expectations of group appropriation below the threshold decrease appropriation. We also find evidence of a behavioral difference between the two groups of subjects. Controlling for behavior in the benchmark game, differences in the appropriation decisions among subjects who are more pessimistic about the level of group appropriation are found to be more systematically related to differences in expected marginal net benefits in comparison to those with more optimistic beliefs.

The paper is organized as follows. In section 2, we describe the decision setting and parameters of the games investigated. Section 3 provides a theoretical discussion, including behavioral conjectures. Section 4 presents the experimental results and Section 5 provides a discussion of results and conclusions.

## **2 Decision settings and parameters**

The experimental design included four one-shot decisions from a menu of DPD games (part A) and an incentivized first-order belief-elicitation task related to each of the DPD games (part B). In Part A, incentives in all DPD games are measured in Experimental Currency Units (ECUs). In these games, groups of  $n=4$  individuals face allocation decisions between a “Group Fund” and an “Individual Fund.” Each 4 member group begins with a Group Fund endowment of  $t = 100$  tokens, where every token left in the Group Fund has a value of  $g = 2$  ECUs. Each individual begins the game with 0 tokens allocated to their Individual Fund. Individuals privately decide

how many tokens to appropriate from the Group Fund which are then placed in their Individual Fund, with a maximum appropriation limit of  $e = 25$  tokens per individual.<sup>4</sup> Each token an individual  $i$  appropriates from the Group Fund, in a given treatment condition  $j$ , yields a private benefit increasing the value of his/her Individual Fund by  $h = 1$  ECU. Each token left in the Group Fund has a value of  $g/n = 0.5$  ECUs for every member of the group and thus appropriation generates a *deterministic degradation* to the group of  $g$ . Concurrently, appropriation generates a *probabilistic degradation*, implemented as a hazard rate that depends on the aggregate number of tokens appropriated from the Group Fund. Subjects confront a fractional loss  $L$  of the total value remaining in the Group Fund after all decisions are final. The endogenous probability of this loss occurring is  $(p \sum_{i=1}^n z_i)$ , where  $p=0.01$  is the fractional increase in the probability associated with each token appropriated from the Group Fund. The feasible range of values of  $p \in [0,1]$  and  $L \in [0,1]$ .

Letting  $z_{ij}$  denote the amount individual  $i$  appropriates from the Group Fund in treatment  $j$ , equation 1 presents the payoff to individual  $i$  in ECUs. The probabilistic degradation externality is described in the last component of equation 1.

$$\pi_i^j = h z_{ij} + \frac{g}{n} t - \frac{g}{n} \sum_{i=1}^n z_{ij} - \left(\frac{g}{n}\right) [L_j (p_j \sum_{i=1}^n z_{ij}) (t - \sum_{i=1}^n z_{ij})] \quad \text{if } p_j \sum_{i=1}^n z_{ij} < 1 \quad (1)$$

Ceteris paribus, the experimental design varies  $L$  across games, with  $L=0.10, 0.50$  and  $0.90$  and  $p=0.01$  in all cases.<sup>5</sup> We refer to these treatment conditions as  $L10, L50$  and  $L90$ , and the benchmark game as  $L0$ , as shown in Table 1. A total of 111 subjects participated in these sessions.<sup>6</sup>

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<sup>4</sup> The experimental instructions used context neutral terminology. In particular, subjects' decisions were framed as "moving" tokens from the Group Fund to their Individual Fund. The instructions were in German. See the Supplementary Material for an English translation of the instructions.

<sup>5</sup> All values of  $L$  and  $p$  were presented to subjects as percentages.

<sup>6</sup> The number of subjects is not divisible by 4 due to the fact that one participant left one of the sessions during the middle of the instructions. The session continued with each participant making their decisions, without feed-back. In order to calculate payments for the three group members playing with

Based on the payoff functions given in equation 1, the marginal net benefit ( $MNB_i^j$ ) of appropriation for individual  $i$  in treatment  $j$  is:

$$MNB_i^j = \frac{\partial \pi_i^j}{\partial z_i} = h - \frac{g}{n} - \frac{g}{n} L_j p_j (t - 2 \sum_{i=1}^n z_{ij}) \quad \text{if } p_j \sum_{i=1}^n z_{ij} < 1 \quad (2)$$

Notice, the probabilistic nature of the game implies that the sign and magnitude of  $MNB_i^j$  depends on aggregate group appropriation,  $\sum_{i=1}^n z_{ij}$ . Thus, different subjects facing the same parameter values, but with different expectations of others' behavior, will perceive different incentives to appropriate.<sup>7</sup> After accounting for their expectations of the appropriation decisions of other group members, the larger they expect the shared resource to be, the more salient is the potential of the loss. This makes it crucial for the experimental design to elicit subjects' first order beliefs on group appropriation, as done in part B.

The game instructions for each game, as well as quizzes to check subjects' understanding of the games, were presented sequentially. After participants finished the quiz for a particular game, the experimenter collected the quizzes and the correct answers to the quiz were displayed with a projector, read aloud, and questions answered in private. After instructions and quizzes for each game were reviewed, the experimenter displayed a slide with the parameters for all games and distributed the decision sheets. Subjects completed two copies of the decision sheets, one to hand back to the experimenter once all decisions were final and one to keep until the end of part B. As in Brandts and Schram (2001) and BLW, it was the subjects' choice to determine the order in which he/she made decisions in the games of part A.

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that subject, the average of the three remaining group members was used as the appropriation level of the 4<sup>th</sup> group member. At no point during the session did any of the participants raise a question or concern about this one subject leaving the session.

<sup>7</sup> In the benchmark DPD game where  $L=0$ ,  $MNB_i^j$  equals 0.5 independent of expected group appropriation.

Importantly, at any point during decision-making in part A, subjects had the opportunity to review and change any of the choices they had already made. After all participants had time to finalize their decisions, the experimenter announced the end of part A, after which no one was allowed to change their decisions.

Part B was an incentivized belief elicitation task following Croson (2007), in which subjects were asked to report a forecast of the average per-person appropriation level for the other members of their group for each of the four games in part A. Subjects learned of the details of part B only after completing part A, with no feedback of results from part A. While making their forecasts, subjects could refer to the copy of their own decision-making sheet. As discussed below, one game was randomly chosen for payment; if a subject's forecast of the per-person average number of tokens appropriated was equal to or not more than 1 token away from the actual average of the other group members in that game, he/she earned an additional US\$6.8.<sup>8</sup> If the forecast was more than 1 token away from the average, he/she earned US\$2.7 divided by the (absolute) distance between the forecast and the actual average.

Individual earnings from the two parts were calculated independently. To calculate earnings for part A, at the end of the session, the monitor randomly picked one of the 4 games by picking a card out of a shuffled deck of cards numbered from 1 to 4. If the game chosen included probabilistic degradation (which was the case in all but the benchmark game), the monitor also randomly chose a number from a deck of cards numbered 1-100 to determine if groups would incur the loss in value of the Group Fund. In each session, if the number on the card chosen was less than or equal to  $(p \sum_{i=1}^n z_i) * 100$ , the percentage  $L$  was deducted from the value remaining in the

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<sup>8</sup> Earnings in Part B were denoted in Euros. The exchange rate at the time was US\$1.36 for Euro.

Group Fund after appropriation. The calculation of earnings for part B was based on the same decision situation as the one picked for part A. All drawings were made in public. Subjects were paid in private in cash.<sup>9</sup>

### 3 Expected marginal incentives and behavioral conjectures

Equation 2 presents the  $MNB_i^j$  to appropriate as a function of parameter values for the games studied. Table 1 displays the specific functional relation between  $MNB_i^j$  and aggregate group appropriation for each of the treatment conditions  $j=L0, L10, L50$  and  $L90$ .

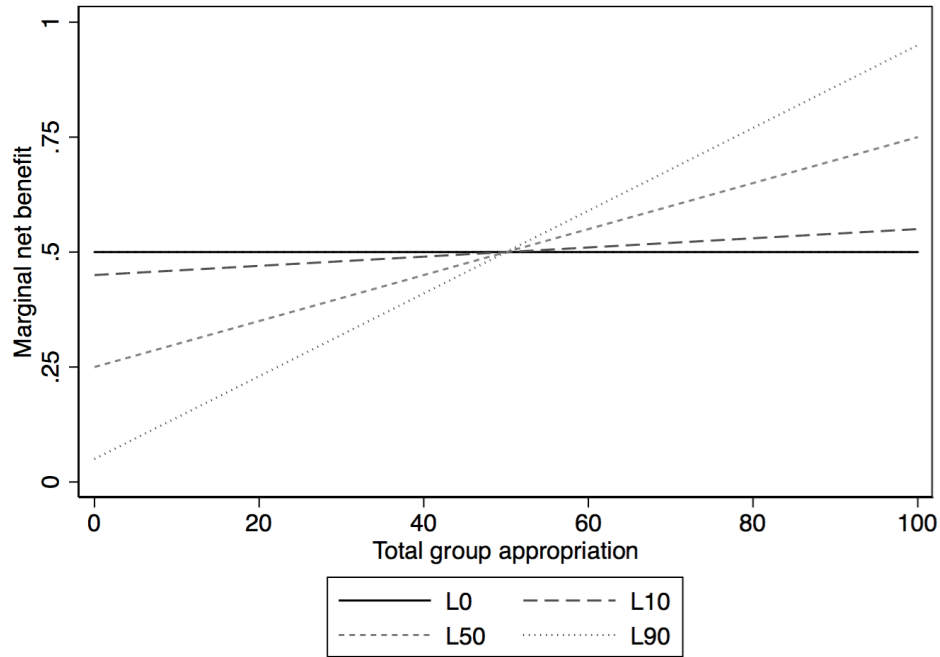
**Table 1.** Decision settings: parameters and marginal net benefits

Decision Setting	$L$	$p$	Marginal net benefit functions
L0 (benchmark game)	0	0.01	$MNB_i^{L0} = 0.5$
L10	0.1	0.01	$MNB_i^{L10} = 0.45 + 0.001 \sum_{i=1}^n z_i$
L50	0.5	0.01	$MNB_i^{L50} = 0.25 + 0.005 \sum_{i=1}^n z_i$
L90	0.9	0.01	$MNB_i^{L90} = 0.05 + 0.009 \sum_{i=1}^n z_i$

Parameters  $n=4, t=100, e=25, h=1$  are constant in all games.

Figure 1 illustrates the general functional form for  $MNB_i^j = \frac{2}{4}(1 - L * 0.01(100 - 2 \sum_{i=1}^n z_i))$ .

<sup>9</sup> In addition to the two parts described in the text, subjects participated afterwards in a risk aversion task and a dictator donation to a set of NGOs. Subjects learned the details of these tasks after finishing decisions for Part B. The behavior in these two parts was not found to be significantly correlated with game decisions. For brevity, these results are not reported. Total earnings were the sum of earnings for each of these four parts. On average subjects total earnings were 15.6 Euros during the experiment which lasted about 60 minutes.



**Fig. 1** Marginal net benefits as a function of aggregate group appropriation

For any value of  $L$  in the range  $[0, 1]$ , the unique Nash equilibrium for self-interested payoff-maximizing agents is to appropriate at capacity. This follows from the observation that the  $MNB_i^j$  is positive for all treatment conditions and for all possible levels of group appropriation, as illustrated in Figure 1.

Aiming to contribute to the literature analyzing the relevance to behavior of variations in marginal incentives in social dilemma games, a primary focus of this study is the nature of behavior out of equilibrium. A broad range of previous research on social dilemma settings has shown the self-interested payoff-maximizing assumptions to be descriptive of the preferences of only a subset of subjects in standard subject populations. This research has demonstrated that individuals' decisions in a variety of social dilemma situations reflect complex and diverse motivations beyond simple self-income maximization (see research summarized in Camerer 2003; Camerer and Fehr 2006; Ostrom and Walker 2003). In addition, an

important subset of this research has shown that subjects respond to changes in marginal incentives to cooperate (not cooperate). Previous studies addressing the behavioral response to endogenous probabilistic losses have indirectly or only partially estimated the expected marginal incentives. Walker and Gardner (1992) focus on game continuation, and not on individual subject responses to expectations of marginal incentives. Analyses in the provision games studied by Dickinson focuses on lagged expected per capita return, thus implicitly assuming that expectations of current round group contributions are based on group contributions of the previous round. In treatment condition 7 of Gangadharan and Nemes (2009), which is the closest to this study, subjects face both exogenous and endogenous uncertainty over the probability of receiving a return from investments in providing the group good. In analyzing behavior in this treatment condition, the authors focus on one-period lagged group contributions as a measure of current round expectations. As in BLW, our study explicitly links expected value of  $MNB_i^j$  in a treatment  $j$  to subjects' forecast of other group member's appropriation. Unlike BLW, however, in the appropriation games in this study, marginal incentives to appropriate vary with  $L$  across treatment manipulations. This aspect of the design allows us to address the implications of changes in expected marginal incentives to appropriate across and within games.

Focusing on expected marginal benefits from appropriation relative to those of the benchmark game leads to two conjectures regarding subject behavior. Conjecture 1 addresses the relevance of the threshold of 50 tokens in qualitatively separating the response to the treatment conditions as compared to behavior in the benchmark game.

**Conjecture 1:** In games with probabilistic degradation, subjects who expect group appropriation to be above (below) 50 will increase (decrease) appropriation as compared to their decision in the benchmark game.

Figure 1 illustrates the relevance to  $MNB_i^j$  of the threshold  $\bar{Z} = 50$  tokens of group appropriation. In particular, below  $\bar{Z} = 50$  the  $MNB_i^j$  from appropriation in  $j=L10, L50, L90$  is lower than in the benchmark game. Above  $\bar{Z} = 50$ , the  $MNB_i^j$  from appropriation is higher than in the benchmark game. In addition, holding expectations of group appropriation constant, the absolute differences between  $MNB_i^j$  in the treatment conditions and the benchmark game increase as  $L$  increases.

Next, Conjecture 2 describes the response to the change in the *magnitude* of marginal incentives with variations in expected group appropriation and parameter  $L$  relative to behavior in the benchmark game.

**Conjecture 2:** Compared to their decision in the benchmark game, a subject's appropriation decision in games with probabilistic degradation will be positively related to her individual expected  $MNB_i^j$ .

This is a more straightforward test of the responses to expected  $MNB_i^j$ , which depends on each subject's expected group appropriation. However, comparing the magnitude of the responses to expected  $MNB_i^j$  across treatments requires a transformation of the marginal incentives into percentage changes. This transformation is motivated by the fact that the range of values of  $MNB_i^j$  as a function of group appropriation increases with the size of  $L$ . In particular,  $MNB_i^{L0} = 0.5$ ,  $MNB_i^{L10} \in [0.45 \text{ to } 0.55]$ ,  $MNB_i^{L50} \in [0.25 \text{ to } 0.75]$ ,  $MNB_i^{L90} \in [0.05 \text{ to } 0.95]$ .

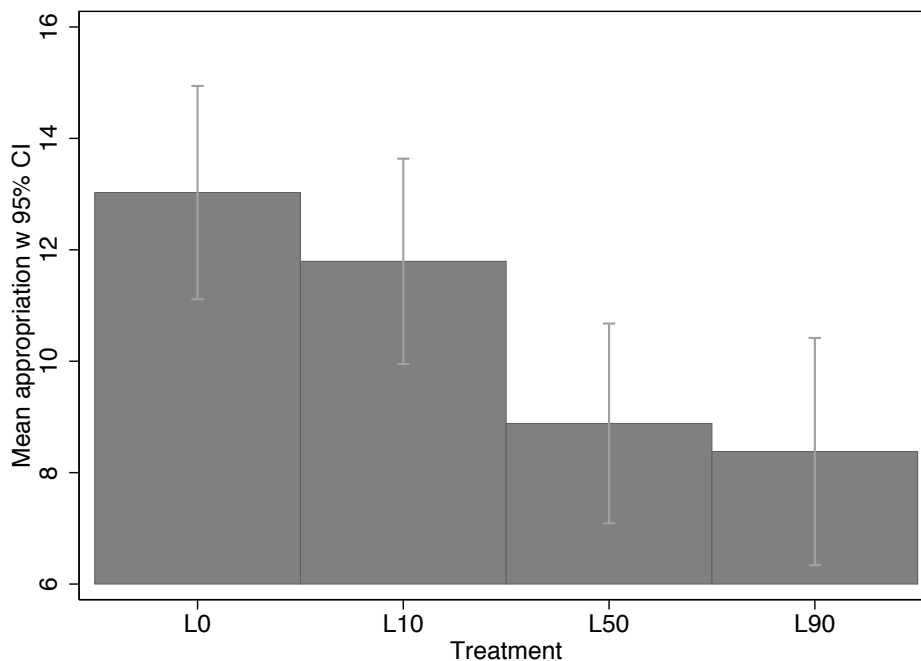


## 4 Experimental results

The discussion of results begins with an overview, which is then followed by tests of the behavioral conjectures. Because the decision situations are one-shot and subjects did not receive feedback information until all decisions were final, the presentation of results is based primarily on individual decisions as opposed to group decisions. First, summary results associated with the changes in treatment conditions are provided.

Next, we examine to what extent a subset of subjects make decisions strictly consistent with equilibrium predictions in all treatment conditions. Finally, we examine to what extent the behavior of subjects can be associated with the expected level of  $MNB_i^j$ . We do so by examining appropriation decisions below and above the threshold of 50 tokens (conjecture 1) and the response to the expected marginal net benefits to appropriate (conjecture 2).

Pooling across individuals, Figure 2 provides mean appropriation levels (and 95% confidence intervals) of the individual appropriation decisions. The primary conclusion is that, on average, aggregate appropriation decreases as  $L$  increases.



**Fig. 2** Average appropriation across treatment conditions

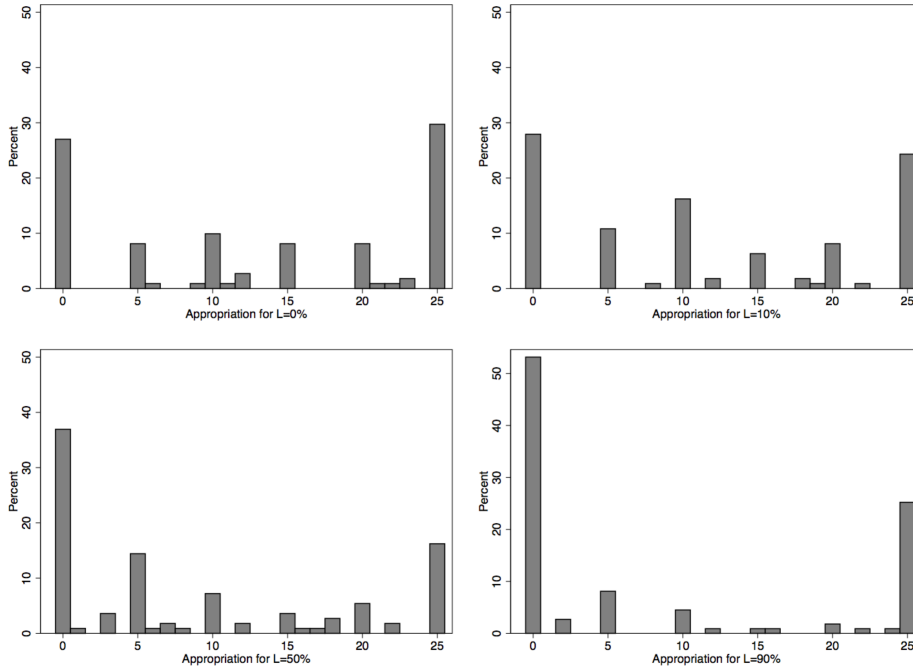
Table 2 presents the associated average pairwise changes in individual behavior across treatment conditions. All comparisons are significantly different, except for the difference between L90 and L50.

**Table 2.** Mean paired differences across treatment conditions

	L10-L0	L50-L0	L90-L0	L50-L10	L90-L10	L90-L50
Mean difference	-1.234 (0.062)	-4.144 (0.000)	-4.649 (0.000)	-2.910 (0.000)	-3.414 (0.000)	-0.505 (0.411)
<i>N</i>	111	111	111	111	111	111

Paired t-tests, p-values in parentheses

Figure 3 complements Figure 2 by providing the frequency of appropriation in each treatment condition. As expected, in the histogram for  $L0$  (where only deterministic degradation exists, and marginal net benefits from appropriation are constant at 0.5) there is a substantial diversity in subjects' decisions. In particular 30% of the subjects appropriate at capacity, and 27% appropriate at a level of 0. Consistent with other one-shot social dilemma games, the variability in behavior in the benchmark setting of  $L0$  provides evidence of heterogeneity in underlying predispositions toward cooperativeness that are not associated with changes in marginal incentives within the game. The changes in distributions of decisions displayed in Figure 3 provide further evidence related to the responses to the treatment conditions. As the value of  $L$  increases there is evidence of a polarization of decisions in maximum and minimum appropriation strategies. Despite the large proportion of subjects appropriating at capacity in every treatment condition, only 14% of subjects appropriate at capacity in all treatment conditions.



**Fig. 3** Frequency of appropriation decisions across treatment conditions

For testing conjectures 1 and 2, the within-subject structure of the data is used by focusing on changes in individuals' decisions across treatments relative to their decisions in the benchmark game. This allows for testing for treatment effects controlling for the baseline appropriation (subjects' cooperativeness) where marginal incentives are independent of group appropriation.

Conjecture 1 states that as compared to  $L0$ , appropriation in a given treatment will increase for subjects who expect aggregate group appropriation to be above the critical threshold  $\bar{Z} = 50$  and decrease for those whose expectations are below  $\bar{Z} = 50$ . Table 3 presents results from OLS regressions for each treatment condition, where the dependent variable is the difference in a subject's appropriation in the benchmark game  $L0$  and in each of the three treatment conditions. Conditional on the treatment condition, the independent variable,  $\bar{Z} > 50$ , is a dummy variable

having a value of one if expected group appropriation for a subject is above 50, and zero otherwise.

As shown in Table 3, for the subjects who expect group appropriation to be less than or equal to 50 (the constant term), the mean differences in appropriation relative to the benchmark game are negative and significantly different from zero. As shown, the constant term also becomes significantly more negative as  $L$  increases.<sup>10</sup> This latter result is consistent with two effects. First, below the threshold, holding constant expectations of group appropriation, marginal net benefits to appropriate decrease as  $L$  increases. Second, for this group of subjects, there is a significant decrease in expected group appropriation associated with increases in  $L$ , which results in turn in decreased marginal net benefits to appropriate.<sup>11</sup>

Similarly, for subjects with expected group appropriation above 50, we observe greater appropriation than in the benchmark game, in particular 1.863 tokens for L10, 2.581 for L50, and 6.289 for L90. The coefficients on the variables  $\bar{Z} > 50$  are positive and significantly different from zero for all paired comparisons. In addition, these coefficients are increasing as  $L$  increases, but not significantly different in all cases.<sup>12</sup> This lack of significant differences across games is consistent with the finding that, for subjects with expectations of group appropriation above 50, changes in expected group appropriation associated with increases in  $L$  are not strongly significant.<sup>13</sup>

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<sup>10</sup> p-values for corresponding Wald tests on changes in the constant term: L10 vs. L50 (0.000), L50 vs. L90 (0.001), L10 vs. L90 (0.000)

<sup>11</sup> p-values for corresponding t-tests for differences in expected group appropriation: L10 vs. L50 (0.1031), L50 vs. L90 (0.000), L10 vs. L90 (0.000).

<sup>12</sup> The differences are significant in relation to columns 1 and 3 and columns 2 and 3, but not columns 1 and 2. p-values for corresponding Wald tests: L10 vs. L50 (0.577), L50 vs. L90 (0.006), L10 vs. L90 (0.004)

<sup>13</sup> p-values for corresponding t-tests for differences in expected group appropriation: L10 vs. L50 (0.999), L50 vs. L90 (0.139), L10 vs. L90 (0.087).

**Table 3.** OLS: Differences in appropriation between L0 and treatment conditions

	(1)	(2)	(3)
	L10-L0	L50-L0	L90-L0
$\bar{Z} > 50$	5.132 (0.000)	9.331 (0.000)	15.77 (0.000)
Constant	-3.269 (0.000)	-6.750 (0.000)	-9.481 (0.000)
$N$	111	111	111
$R^2$	0.134	0.175	0.363

p-values in parentheses. The number of subjects with expectations above the threshold is 44 in column 1, 31 in column 2 and 34 in column 3. Below the threshold the corresponding values are 67 in column 1, 80 in column 2, and 77 in column 3.

In sum, we find strong support for conjecture 1. Controlling for subjects' decisions in the benchmark game, individual appropriation *decreases* if expected appropriation is below 50, and individual appropriation *increases* if expected appropriation is above 50. In addition, this effect is stronger for larger values of  $L$ .

Moving to conjecture 2, recall that this conjecture relates to subjects' responses to changes in the  $MNB_i^j$  between treatment conditions. Table 4 presents results from OLS regressions for differences in appropriation between decisions in a given treatment condition and the benchmark game. The independent variable for each regression is REL-MNB, a linear transformation of the individual expected  $MNB_i^j$  that takes values from 0 to 1, and is equal to 0 if the expected  $MNB_i^j$  is at its lowest possible value in a given treatment and is equal to 1 if expected  $MNB_i^j$  is at its highest possible value in a given treatment. As noted in section 3, this transformation allows for comparability of the coefficients across treatment conditions.<sup>14</sup> Note that

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<sup>14</sup> This variable is constructed by first calculating expected  $MNB_i^j$  for each subject, conditional on expectations of total group appropriation. The variable is then normalized to be between 0 and 1 by subtracting from each value the minimum possible value of  $MNB_i^j$  in the treatment, and then dividing that value by the difference between the maximum and the minimum possible values of  $MNB_i^j$  in the

the constant term captures appropriation decisions at a value of REL-MNB of zero, associated with expected group appropriation equal to zero.

Table 4 shows a positive and highly significant coefficient for REL-MNB in all treatment conditions. Further, based on the intercept terms, we observe a significant mean reduction in appropriation in each treatment condition relative to the benchmark game. Comparisons across treatments show both the constant term and the coefficient of REL-MNB significantly increase in absolute magnitude as  $L$  increases.<sup>15</sup> In summary, there is strong support for conjecture 2. In relation to behavior in the benchmark, at minimum levels of  $MNB_i^j$ , subjects significantly decrease appropriation in the games with probabilistic degradation. In addition, as expectations of group appropriation increase (and associated values of  $MNB_i^j$  increase) appropriation increases and surpasses the level of appropriation observed in the benchmark game.

**Table 4.** OLS: Differences in appropriation between L0 and treatments

	(1) L10-L0	(2) L50-L0	(3) L90-L0
REL-MNB	8.082 (0.000)	14.99 (0.000)	21.08 (0.000)
Constant	-4.914 (0.000)	-9.613 (0.000)	-11.58 (0.000)
$N$	111	111	111
$R^2$	0.114	0.194	0.387

*p*-values in parentheses

treatment. Thus, the variable measures the relative size of  $MNB_i^j$  in a treatment conditional on expected group appropriation. For example, for treatment L10 the variable is constructed for each individual as  $(MNB_i^{L10} - 0.45)/(0.55 - 0.45)$ .

<sup>15</sup> *p*-values for corresponding Wald tests on changes in the constant term: L10 vs. L50 (0.008), L50 vs. L90 (0.000), L10 vs. L90 (0.000).

*p*-values for corresponding Wald tests on changes in the coefficient: L10 vs. L50 (0.000), L50 vs. L90 (0.003), L10 vs. L90 (0.000).

A natural extension of the analysis above is to examine whether the responses to changes in expected marginal incentives are symmetric for subjects whose expectations of group appropriation are above and below the threshold of  $\bar{Z} = 50$ . Table 5 presents results from OLS regressions that parallel the approach presented in Table 4, except that the analysis is conducted separately for subjects with expected group appropriation in a given treatment above 50 and for those with expectations below or equal to 50. This analysis requires the computation of a new independent variable REL-MNB(DIFF). First, based on expected group appropriation, we compute the absolute value of expected  $MNB_i^j$  minus 0.5 (the  $MNB_i^j$  at  $\bar{Z} = 50$ ). This value is then divided by the maximum possible change in  $MNB_i^j$  in a given condition.<sup>16</sup> Thus, the variable takes on values between 0 and 1, and the constant term provides information on the appropriation levels at the threshold of 50 tokens, where REL-MNB(DIFF) = 0.

**Table 5.** OLS: Differences in appropriation between treatments and the benchmark game

	EXOECTIONS ABOVE 50			EXPECTATIONS BELOW 50 <sup>a</sup>		
	(1) L10-L0	(2) L50-L0	(3) L90-L0	(4) L10-L0	(5) L50-L0	(6) L90-L0
REL-MNB(DIFF)	7.124 (0.055)	9.468 (0.052)	10.06 (0.020)	1.896 (0.327)	-3.519 (0.279)	-5.658 (0.141)
Constant	-1.755 (0.215)	-2.229 (0.346)	-0.0499 (0.981)	-4.182 (0.001)	-4.737 (0.032)	-5.115 (0.092)
<i>N</i>	44	31	34	67	80	77
<i>R</i> <sup>2</sup>	0.091	0.133	0.128	0.010	0.016	0.028

*p*-values in parentheses; <sup>a</sup> includes subject with expectations exactly at 50 tokens.

<sup>16</sup> The maximum possible change in  $MNB_i^j$  in each treatment condition for subjects with expected appropriation below or equal to 50 is based on the difference in  $MNB_i^j$  for expected appropriation at 50 and at zero, and for subjects with expected appropriation above 50 is based on expected appropriation at 50 and at 100. For example, for a subject in treatment L10 with expected appropriation below the threshold, REL-MNB(DIFF) is calculated as  $(MNB - 0.5)/(-0.05)$ .

Comparing columns 1-3 to columns 4-6 reveals that the response to changes in  $MNB_i^j$  by subjects with expectations of group appropriation above and below the threshold of  $\bar{Z} = 50$  is qualitatively different. In particular, for subjects with expected appropriation above the threshold the coefficient for REL-MNB(DIFF) is significantly different from zero in each treatment condition. For subjects with expected appropriation below the threshold, however, the coefficients for REL-MNB(DIFF) are not significantly different from zero. In addition, as expected, the constant terms in columns 1-3 are not significantly different from zero. Somewhat unexpected, however, in columns 4-6, all constant terms are negative and significantly different from zero with the absolute magnitude growing as  $L$  increases across treatments. In summary, these results suggest that support found for conjecture 2 is driven mainly by subjects for whom expected group appropriation is above the threshold of 50 tokens.

In addition to net benefits from appropriation, it is relevant to understand the implications of changes in the magnitude of the loss ( $L$ ) in economic efficiency ( $\varepsilon$ ) calculated at the group level in each game. For this purpose, in the baseline game, efficiency is defined as

$$\varepsilon^{L0} = (P_{L0} - \min P) / (\max P - \min P) \quad (7)$$

where  $P_{L0}$  is the average group payoff for  $L0$ ;  $\min P$  is the minimum possible payoff, which corresponds to the payoffs at the Nash equilibrium; and  $\max P$  is the maximum possible payoff, the social optimum. For treatments L10, L50, and L90, one must account for the potential probabilistic loss of earnings resulting from aggregate group appropriation. Thus, in the games with probabilistic degradation, efficiency is calculated by using the expected value of group earnings based on average group



appropriation. Note, at the social optimum the probability of loss occurrence is zero, and if subjects appropriate to full capacity there is a 100% probability of degradation. In this case, however, because the Group Fund is fully exploited, the probabilistic degradation is irrelevant. Finally, notice that for the same level of appropriation in games with probabilistic degradation, expected efficiency will be lower than in the baseline game due to the probabilistic loss associated with appropriation.

The reported differences in individual appropriations between decision settings results in clear differences in efficiencies. In the baseline game efficiency is 47.89%, and increases monotonically to 52.83%, 64.47%, and 66.49% as  $L$  increases from L10 to L50 and L90.

## **5 Discussion of results and conclusions**

This study investigates behavior in an experimental setting where subjects confront social dilemma appropriation games that include both deterministic degradation and probabilistic degradation of a loss of a shared resource. Deterministic degradation implies a fixed marginal loss in value of the group fund associated with each unit of appropriation. Probabilistic degradation implies an endogenous probability of a percentage loss in the remaining value of the group fund after the group has made its appropriation decisions. Importantly, the probability of the loss occurring increases in aggregate group appropriation. An implication is that the expected marginal net benefits of appropriation depend on the subjects' expectation of appropriation of other group members. For control purposes, a benchmark game is included in which subjects face only deterministic degradation of the shared resource, and therefore provides information on initial “baseline” cooperation levels.

The primary focus of the research design is to examine how subjects respond to parametric changes in the percentage loss in group funds as it is varied across games that include probabilistic degradation. On average we find that aggregate group appropriation decreases as  $L$  increases, and expected efficiency increases. We also observe, however, important heterogeneities in individual behavior. Controlling for individual decisions in the benchmark game, we find that subjects who expect that the shared resource will be substantially exploited increase their level of appropriation. The opposite holds true for subjects who believe that other group members will refrain from appropriation. We also examine to what extent subjects' appropriation decisions can be directly linked to perceived changes in the marginal net benefits of appropriation, which are endogenous to their expectations of others' appropriation. We find a behavioral difference between those subjects who expect higher levels of group appropriation versus those who expect lower levels of group appropriation. In particular, within game settings, subjects who are more pessimistic regarding others' appropriation respond more systematically to changes in expected marginal net benefits of appropriation.

To our knowledge, these are the first experiments to examine subjects' responses to variations in endogenous probabilistic degradation. Overall, the results indicate the importance of heterogeneous endogenous expectations of others' behavior in these settings and the associated net marginal benefits of appropriating. The institutional setting for these experiments is stark in the sense of subjects not having opportunities to repeat play or learn from a history group decisions. We argue that this type of setting captures many field settings in which institutions that can facilitate cooperation do not exist and/or individuals decisions in the field are anonymous. Gaining an understanding of individual responses to changes that impact

probabilistic catastrophic degradations is fundamental in designing conservation programs whose intention is to ameliorate inefficiencies and/or avoid the destruction of natural resources and the ecosystem services provided by the resource. As this study demonstrates, individuals may have both heterogeneous responses and beliefs regarding how others will respond to the potential of an endogenous destruction of ecosystem services. Thus, cost-effective conservation programs will need to embrace this heterogeneity in designing effective institutions.

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Esther Blanco, Tobias Haller, James M. Walker

Externalities in appropriation: Responses to probabilistic losses

**Abstract**

We examine behavior in one-shot appropriation games with deterministic and probabilistic degradation externalities, where the marginal net benefit from appropriation is endogenous, dependent on individuals' expectations of group appropriation. The experimental design involves a menu of games where the magnitude of a loss parameter associated with probabilistic degradation varies across games. On average, as the loss parameter increases we observe a significant reduction in group appropriation. There is, however, considerable heterogeneity in behavior. First, subjects who are more pessimistic (optimistic) about group appropriation significantly increase (decrease) appropriation as the loss parameter increases. Second, relative to subjects with more optimistic expectations regarding group appropriation, the appropriation of subjects who are more pessimistic is more closely tied to changes in expected marginal benefits.

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