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Collective Risk-Taking in the Commons

Olivier Bochet*, Jeremy Laurent-Lucchetti†, Justin Leroux‡, Bernard Sinclair-Desgagné§

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Abstract

The management of natural commons is typically subject to threshold effects. If individuals are risk-averse, some of the recent economic literature holds that uncertainty on the threshold may have a positive impact by lowering incentives to over-consume. By contrast, this intuitive result may unravel when uncertainty is modeled as a discrete or multimodal distribution. Using a variant of the Nash demand game with two thresholds, two types of Nash equilibria typically coexist: *cautious (respectively, dangerous) equilibria* in which agents coordinate on the low threshold (resp. the high threshold). When both types of equilibria coexist, the symmetric dangerous equilibrium is always Pareto dominated by the symmetric cautious equilibrium, and the latter is always Pareto efficient. We use an experimental setting to assess the severity of the coordination and equilibrium selection problem. While cautious (resp. dangerous) play is decreasing (resp. increasing) in the probability that the threshold is high, coordination failures are salient for intermediate probabilities where the likelihood of coexistence of both type of equilibria is high. We find that there is a U-shaped relationship between overall coordination and the probability that the threshold is high.

Keywords: Common-pool resources, Uncertain Thresholds, Nash Demand Game.

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1 Introduction

It is well known since the works of Olson (1965) and Hardin (1968), on the one hand, and of Schelling (1978), on the other hand, that (i) group behavior can lead to inefficient outcomes in the form of wasted resources (over-harvesting, over-pollution) or forgone opportunities (under-provided public good), and (ii) attributes (like risk aversion) shared by most individual group members might not apply to the group as a whole. As it turns out, both problems can appear simultaneously when the commons problem is compounded by the presence of uncertainty about what is really available.

Speaking of such commons, the global climate immediately comes to mind: climate scientists point to irreversible harm that may occur past a given accumulation of greenhouse gases in the atmosphere, but they also disagree on the precise threshold. Similar situations exist elsewhere. In public health, notably, some diseases become epidemic past a threshold of infected people, but there is uncertainty about this threshold; some pathogens become resistant to antibiotics past an (uncertain) level of collective use of a specific drug.[1]

These examples embody three well-documented stylized facts: first, common-pool resources provide services subject to discontinuities, bifurcations or threshold effects that may show up rather abruptly following persistent abuses (Scheffer et al. 2001; Rockström et al. 2009); second, the inherent complexity of some common-pool resources makes the assessment of a precise threshold uncertain; third, individual users can protect against risk by collectively reducing their consumption. Accordingly, we may see them as variants of a modified Nash demand game (Nash, 1950; henceforth NDG) in which there is uncertainty about the amount players can split. In the simplest instance of this game, uncertainty about the resource is represented as a Bernoulli distribution which is known to all, with low and high resource amounts bearing respective probabilities $(1-p_h)$ and p_h.[2] The resource truly available is revealed *ex post*, after agents have committed *ex ante* on their respective claim; everyone gets zero if aggregate demand then exceeds capacity.

In this stylized context, multiple sets of equilibria can coexist (Proposition 1). In

[1] For more examples we refer the reader to Laurent-Lucchetti et al, 2013.

[2] Our theoretical results are qualitatively robust to the presence of an arbitrary finite number of potential thresholds. They hold as well if uncertainty concerning the location of thresholds is captured by a continuous but multimodal probability distribution. See the online appendix for details, https://sites.google.com/site/obochet2/onlineappendixcautious.pdf.

what we call *cautious equilibria*, agents collectively ask for splitting the lowest amount, thereby guaranteeing that their respective individual claims are met. In what we call *dangerous equilibria*, agents collectively ask for the high resource level, thereby exposing themselves to a probability p_h of collapse.[3] When both types of equilibria coexist, every cautious equilibrium is Pareto efficient and Pareto-dominates all dangerous equilibria that can be reached from it while increasing every agent's claim (Propositions 2 and 3). In particular, the *symmetric cautious equilibrium* always Pareto-dominates the *symmetric dangerous equilibrium*. It therefore happens that all agents would be better off taking less risk, but that strategic interaction prevents them from doing so, even if they all are risk averse.[4]

These theoretical conclusion run counter to the existing theoretical literature on commons problems, which holds that widely spread risk aversion should translate into somewhat cautious collective behavior in the presence of exogenous risk. This departure can be attributed to representing uncertainty as a discrete or multimodal distribution instead of the more usual continuous unimodal one. Behaviorally, though, it is subject to one major caveat. A central issue with the standard NDG is that the size of the set of Nash equilibria entails coordination issues: agents have to settle on claims which precisely sum up to the available amount. This coordination problem occurs '*within' the set of equilibria*. Our stochastic NDG now introduces an additional coordination problem *'between' sets of equilibria*, since dangerous and cautious equilibria coexist. How agents actually solve both problems at the same time is far from clear, so we turn to an experiment to test the model's prediction. A priori, our conjecture is that, in the lab, coordination problems within equilibria will not be as serious as coordination problems between equilibria, because agents can alleviate the former by focusing on an equal split of the resource. To our knowledge, this is the first time these two coordination issues are identified and investigated simultaneously.

Our experimental results end up confirming the theoretical findings: both types of equilibria coexist in the lab, even when all agents in a group are risk-averse. Among the expected findings, we find that cautious (resp. dangerous) play is decreasing (resp. increasing) in p_h. But what about the coordination and equilibrium selection problem?

[3] A third set of equilibria exists, named *dreadful equilibria*. In a dreadful equilibrium, agents collectively claim so much of the resource that no unilateral deviation by someone can prevent exhaustion. These equilibria always exist, even in the standard NDG. Intuitive equilibrium refinements, like the Strong Nash Equilibrium which allows group deviations, can eliminate them.

[4] There obviously are parameter constellations for which only dangerous equilibria exist –e.g. when the probability p_h is very high. In this case, dangerous equilibria are always Pareto efficient.

We run five treatments, each with a fixed probability $p_h \in \{0.3, 0.5, 0..7, 0.9, 0.99\}$. For the treatments with more extreme values, $p_h = 0.3$ (resp. $p_h = 0.99$), subjects coordinate on an equilibrium play in 70% (resp. 78%) of the cases. In contrast subjects experience difficulty in coordinating on equilibrium play for intermediate values of p_h, where the likelihood of coexistence of cautious and dangerous equilibrium is high. Coordination failures are salient for such an intermediate $p_h = 0.7$, where the rate of coordination failure is around 72% (put differently, equilibrium play whether it is cautious and dangerous is around 28%). By contrast, such a rate falls down to, respectively, 50% when $p_h = 0.5$ and 40% when $p_h = 0.9$. The probability p_h thus plays an important role in achieving coordination towards an efficient outcome. In conjunction with the above discussion, one of our main result is to find a U-shaped relationship between overall coordination and p_h. This type of pattern remains for other type of coordination failures. For instance, the impact of coexistence of equilibria on coordination is also reflected in the average payoff of subjects which depicts the same U-shaped relation with p_h. Similarly, overshooting (understood as a sum of demands that exceeds the realized threshold) is inverted U-shaped linked to p_h.[5]

On the policy side, these findings stress once again the key role of information in the management of common-pool resources. Absolute consensus on the precise threshold location is not necessary for an efficient outcome to be implemented in a decentralized fashion. What matters is that agents (with possibly different utility functions) hold the same representation of uncertainty, and that the low threshold be sufficiently likely.

Related Literature: Our theoretical results depart from the established and somewhat intuitive view that the presence of uncertainty can help discipline risk-averse agents, thus mitigating the hazards of group behavior. In different frameworks, Eso and White (2003), White (2004), and Bramoullé and Treich (2009) have indeed shown that, despite internal strategic interactions, uncertainty leads groups of risk-averse agents to be more cautious collectively. In a first-price sealed-bid auction, for instance, it is well-known that risk-averse agents will bid aggressively in order to reduce the risk of losing the object; but when the value of the object is uncertain, risk-averse agents (of the DARA type) become less aggressive and are better-off as a result. Eso and White (2003) call this 'precautionary bidding.' Bramoullé and Treich (2009) reach an analogous conclusion in considering a version of the commons problem where the (continuous)

[5]We thank an anonymous referee for suggesting that we investigate these U-shaped relationships.

damage function is subject to exogenous risk. They show that risk-averse individuals would act more conservatively so as to avoid large variances in payoffs, thus mitigating the tragedy of the commons. The reason our analysis delivers opposite results from these papers is that their authors consider unimodal distributions, while we postulate a multimodal one. Multimodal distributions are likely to arise in the contexts mentioned above (climate change, epidemiological outbreaks, antibiotic resistance, etc.) as the outcome of aggregating the assessments of disagreeing experts.[6] With multimodal distributions, the set of equilibria might significantly expand, so equilibrium selection gets more complicated.

In a setting relatively close to ours, Guth et al. (2004) study an NDG with two players and an uncertain surplus size. However, they allow each party to choose to 'wait' until uncertainty is resolved before making a claim. Adding the 'wait' strategy yields two equilibria in which one of the players takes almost the whole surplus, provided uncertainty is small. Another related contribution is Barrett and Dannenberg (2012), who demonstrate theoretically and observe in the lab that the combination of uncertainty and thresholds effects transforms the traditional free-riding problem of the tragedy of the commons into a coordination problem. As soon as the value of the threshold is uncertain, coordination breaks down dramatically and catastrophe cannot be avoided. Our analysis differs from theirs in at least two important ways: (i) they assume agents are risk neutral while we highlight the presence of risk aversion, (ii) they suppose the probability of catastrophe varies uniformly with the group's activity level while we keep the probability distribution exogenous and constant. These differences allow us to draw specific conclusions: namely, that coordination on the safe level of activity is possible if the probability of catastrophe is sufficiently high, but that such coordination is quite hard when this probability is low, even if all agents are risk-averse.

Diekert (2017) recently examined a tractable dynamic version of an NDG with threshold uncertainty, which parallels and completes our study: it highlights the possibility for agents to collectively experiment and learn about the threshold's location, while we focus on coordination issues; it uses a theoretical model with identical agents, while we resort to an experiment and allow a heterogenous group of players. Conclusions, though, are in line with the intuitive view: the threat of collapse makes agents collectively more

[6]Combining estimates, forecasts or probability distributions from experts is a traditional and well-researched topic in Management Science. For a critical survey of existing mathematical methods and behavioral approaches, see Clemen and Winkler (1999). The reasonableness and necessity of dealing with multimodal distributions, in particular, is argued on page 192.

careful in searching for the threshold. Our own findings suggest that this proposition may not hold when probabilistic beliefs about threshold location are multimodal.

The division of private goods has already received much attention in the experimental literature investigating the effects of resource uncertainty on cooperative behavior (Budescu et al., 1992, 1995; Rapoport et al., 1992; Suleiman et al., 1994). As in our setting, subjects were free to claim as much as they wanted of a resource, with the consequence that they got nothing if the group's total request exceeded the available resource. The main finding is that, as uncertainty (defined as the range of a uniform probability distribution) increased, subjects overestimated resource size and requested more. These findings are in line with the results of experimental papers on threshold uncertainty in discrete public-good contribution games –McBride (2010) finds that wider threshold uncertainty may also hinder collective action; on common-resource problems in a dynamic setting, Fischer at al. (2004) show that an increase in uncertainty leads to overly optimistic expectations. In these papers and the ensuing literature (see for example Gustafson et al., 1999, Milinsky et al., 2008, Tavoni et al., 2011, or Barrett and Dannenberg, 2012), however, it is unclear why resource uncertainty affects cooperation. Gustasfon et al. (1999) state that "a reason for such overestimation may be that subjects perceive a direct relationship between the central tendency of a probability distribution and its range. Increasing the interval between the lower and upper bounds in of resource size would therefore cause subjects to perceive or infer an increase of the expected value of the resource." Another explanation (Rapoport et al., 1992) is that people would base their estimates of resource size on a weighted average of the lower and upper bounds of its possible realization, with the more desirable upper bound being overweighted so an upward shift in the estimates would result: this explanation is consistent with research demonstrating that agents tend to weigh the desirable outcomes more heavily (see Zakay, 1983).

Recent papers also consider variations of the NDG (see Feltovich and Swierzbinski, 2011, Anbarci and Boyd, 2011, Anbarci and Feltovich, 2012, Birkeland, 2013, and Andersson et al., 2014, among others). But none focuses on the type of uncertainty we consider here. Feltovich and Swierzbinski (2011) find, using experiments, that introducing strategic uncertainty in a NDG has an effect on bargaining outcomes. Anbarci and Boyd (2011) and Anbarci and Feltovich (2012) introduce random implementation in the NDG: with an exogenous probability q one bargainer receives her claim, while the other gets the remainder. More recently, Andersson et al. (2014) study strategic uncertainty. They model a player's uncertainty about another player's strategy as a probability distribution over that player's strategy set. They show that robustness to symmetric strategic uncertainty singles out the (generalized) Nash bargaining solution. By contrast, the uncertainty we introduce here is about the *size* of the resource.

Finally, our paper relates to the vast literature on unstructured bargaining (see Camerer, 2003 for a comprehensive survey). This strand of research mainly seeks to understand process-free solution concepts of bargaining models, such as the Nash bargaining solution. Many early experimental setups (for example Roth and Malouf, 1979) reveal that agents coordinate naturally on an equal split of the resource when sharing a pie of fixed size. According to Roth (1985), "bargainers sought to identify initial bargaining positions that had some special reasons for being credible," and equal sharing is one of them. As in our framework, disagreements may thus occur due to coordination difficulties when multiple focal points exist. In Roth (1985), many of the disagreements boil down to self-serving differences between which focal points should be adopted. Our results are in line with some of these non-alternating-offers experiments where more than one focal point for the division of resources exists. In our experiment, many subjects, instead of making demands that guarantee a feasible and strictly positive outcome that is fair, will prefer to make demands that increase the risk of failure but lead to unequal outcomes favoring them.

2 The Model

We introduce in this section a stochastic version of the NDG for which the value of the resource to be distributed can take two possible values, high and low. These values are common knowledge, and their attached probabilities are also known. In the online appendix, we also present a more general version where multiples values are possible, and also a continuous version with multimodal distributions.[7] The theoretical results presented in this section are robust to these extensions. Because our focus is on a test of the predictions of the model, we stick with the simpler version in this section.

Consider a finite set $N = \{1, ..., n\}$ of agents who must simultaneously decide how much of a resource they will claim for themselves. Overall demand is sustainable up to a limit, but uncertainty lies on the tipping point beyond which the intensity of use becomes unsustainable, which we model as the available resource collapsing to 0.[8] Let

[7]The online appendix is available https://sites.google.com/site/obochet2/onlineappendixcautious.pdf.

[8]One interpretation is that agents are sufficiently long-lived to deem the utility from immediate

$h > \ell > 0$ be respectively the high and low values that the stock of resource can take. With probability $p_h \in [0,1]$, the high value h is realized, with probability $(1 - p_h)$, the low value ℓ is realized.

Denote $x_i \in [0,h]$ agent i's claim, demand or request (we use these terms interchangeably throughout the paper) on the resource, $x = (x_i)_{i \epsilon N} \in [0,h]^n$ a request vector or profile, $X = \sum_N x_i$ total demand, and $X_{-i} = \sum_{j \neq i} x_j$ the sum of all agents' claims except agent i's. Given a profile $x \in [0,h]^n$, we also use the notation $x_{-i} = (x_j)_{j \neq i}$ for the profile of demands of agents other than i. Likewise, we use x_T for the profile of demands of agents that belong to T, and $x_{-T} = (x_j)_{j \in T}$ for the profile of demands of agents that belong to $N \setminus T$, where $T \subseteq N$. The utility agent i derives from being delivered her request x_i is given by $u_i(x_i)$, where the function $u_i(\cdot)$ is concave and nondecreasing. Note that concavity of the utility function implies that agents are risk-averse or risk-neutral. Reaching consumption level x_i is conditional on total demand not exceeding the threshold; otherwise all agents get zero utility, $u_i(0) = 0$ for all i.

Agent i's expected payoff in this stochastic NDG is given by:

$$v_i(x_i, X_{-i}) = u_i(x_i)\mathbb{I}(X \leq l) + p_h u_i(x_i)\mathbb{I}(l < X \leq h), \tag{1}$$

where $\mathbb{I}(\cdot)$ indicates whether the condition within parentheses holds $(= 1)$ or not $(= 0)$. Notice that the classical NDG is the special case of a stochastic NDG in which $p_h \in \{0,1\}$.

Nash equilibrium: A profile of claims $x \in [0,h]^n$ is a (pure-strategy) *Nash equilibrium* if for all $i \in N$, and all $x'_i \in [0,h]$:

$$v_i(x_i, X_{-i}) \geq v_i(x'_i, X_{-i}). \tag{2}$$

Strong Nash equilibrium: A profile of claims $x \in [0,h]^n$ is a (pure-strategy) *strong Nash equilibrium* if there does not exist $T \subseteq N$, and $x'_T \in [0,h]^{|T|}$ such that,

$$v_i(x'_T, x_{-T}) \geq v_i(x_T, x_{-T}) \text{ for all } i \in T, \text{ and} \tag{3}$$

$$v_j(x'_T, x_{-T}) > v_j(x_T, x_{-T}) \text{ for some } j \in T. \tag{4}$$

---

unsustainable resource consumption negligible compared to the lifetime utility of sustained consumption.

This completes the description of the model. We now proceed to the derivation of our main results.

3 Theoretical results

We first characterize the set of Nash equilibria of the stochastic NDG. Later, we will analyze the efficiency properties of these equilibria.

3.1 Nash equilibria

Agent i's best response strategy is as follows. First, consider the case where $X_{-i} > l$:

a) If $X_{-i} \leq h$, agent i can do no better than to request $x_i = h - X_{-i}$ because the remaining agents already collectively demand more than the sustainable threshold l.

b) If $X_{-i} > h$, however, agent i can claim any amount $x_i \geq 0$, because she will end up with a payoff of zero anyway.

Next, consider the case where $X_{-i} \leq \ell$:

a) If $u_i(l - X_{-i}) \geq p_h u_i(h - X_{-i})$, agent i does best by claiming $x_i = \ell - X_{-i}$. Requesting the safe amount $\ell - X_{-i}$ in this case yields a higher (certain) utility than demanding the larger but risky amount $h - X_{-i}$.

b) Similarly, if $u_i(l - X_{-i}) < p_h u_i(h - X_{-i})$, agent i's best response is $x_i = h - X_{-i}$.

This description of the best-response strategies shows that three sorts of Nash equilibria are possible: (1) *cautious equilibria*, in which agents collectively demand the highest safe level, $X = \ell$; (2) *dangerous equilibria*, where agents together request the risky upper ceiling, $X = h$, and face a probability $1 - p_h$ of exhausting the resource; and *dreadful equilibria*, wherein everyone's claim is so high, i.e. $X_{-i} > h$ for all i, that no individual adjustment can avoid their collapse.[9] We define these formally below.

[9]Note that we focus here on pure-strategy Nash equilibria. Although mixed-strategy equilibria exist, it is questionable whether subjects can or wish to engage in adopting mixed strategies.

Cautious equilibrium: An equilibrium profile $x \in [0, h]^n$ is a *cautious equilibrium* if $X \leq \ell$.

Notice that for any cautious equilibrium, payoffs are then always positive regardless of p_h because ℓ is available with certainty—i.e., $v_i(x_i, X_{-i}) = u_i(x_i) > 0$ for all $i \in N$.

Dangerous equilibrium: An equilibrium profile $x \in [0, h]^n$ is a *dangerous equilibrium* if $\ell < X \leq h$.

Notice that for any dangerous equilibrium, $v_i(x_i, X_{-i}) = p_h u_i(x_i)$ for each $i \in N$.

Dreadful equilibrium: An equilibrium profile $x \in [0, h]^n$ is a *dreadful equilibrium* if $X_{-i} > h$ for all $i \in N$.

Dreadful equilibria yield zero utility to all. These equilibria already exist in the classical NDG and are therefore not the focus of our analysis.

Notice that no Nash equilibrium exists in which agents collectively ask for less than l or strictly between l and h. Moreover, cautious, dangerous, and dreadful Nash equilibria can coexist, despite the fact that all agents are risk-averse. This contrasts with the findings reported so far in the literature (see Bramoullé and Treich 2009, for example).

Example 1. *Let there be only two agents, with identical utility function* $u_i(x_i) = \sqrt{x_i}$ *for* $i = 1, 2$*. Suppose* $l = 0.8$*,* $h = 1$*, and* $p_h = 0.8$*. The strategy profile* $x = (0.5, 0.5)$ *is a dangerous equilibrium because* $v_i(0.5, 0.5) = 0.7 \cdot 0.8 = 0.56 > v_i(0.3, 0.5) = 0.54$ *for* $i = 1, 2$*. At the same time, the profile* $x' = (0.4, 0.4)$ *is a cautious equilibrium because* $v_i(0.4, 0.4) = 0.63 > v_i(0.6, 0.4) = 0.77 \cdot 0.8 = 0.62$ *for* $i = 1, 2$*; and* $x'' = (1, 1)$ *is also clearly an equilibrium, a dreadful one which brings each agent's payoff to* 0.[10] ◇

We now introduce the conditions underlying the existence of each type of Nash equilibria. For this, we introduce an additional piece of notation. Let $0 \leq \overline{X}_i \leq \ell$ refer to the *cut-off demand level* of the other agents such that:

[10] Although we exclude such risk attitudes for reasons of tractability, note that all three types of equilibria may also coexist with only risk-loving agents. To see this, simply modify the example by supposing that $i = 1, 2$, $u_i(x_i) = x_i^2$, and $p = 0.4$. One can check that $x = (0.5, 0.5)$ is a dangerous equilibrium, $x' = (0.4, 0.4)$ is again a cautious one, and $x'' = (1, 1)$ is a dreadful equilibrium.

$$
\begin{aligned}
u_i(l - X_{-i}) &> p_h u_i(h - X_{-i}) \quad \text{if } X_{-i} < \overline{X}_i, \\
u_i(l - X_{-i}) &< p_h u_i(h - X_{-i}) \quad \text{if } X_{-i} > \overline{X}_i.
\end{aligned}
\tag{5}
$$

This allows us to make the following preliminary statement.

Lemma 1. *For each i, there always exists a unique cut-off demand level, $\bar{X}_i$.*

Proof. Let $f_i(X_{-i}) \equiv u_i(\ell - X_{-i}) - p_h u_i(h - X_{-i})$. Clearly, $f_i'(X_{-i}) = -u_i'(\ell - X_{-i}) + p_h u_i'(h - X_{-i}) < 0$ because the function u_i is concave. If $f_i(0)$ is non-positive, set $\bar{X}_i = 0$. If $f_i(0)$ is positive, the fact that $f_i(a) < 0$ and that $f_i(.)$ is decreasing and continuous entails that there is a unique $\bar{X}_i > 0$ such that $f_i(\bar{X}_i) = 0$, $f_i(X_{-i}) > 0$ if $X_{-i} < \bar{X}_i$, and $f_i(X_{-i}) < 0$ if $X_{-i} > \bar{X}_i$. $\square$

The following proposition characterizes the existence of cautious and dangerous equilibria.

Proposition 1. *The stochastic NDG always admits at least one non-dreadful equilibrium. More precisely,*

i) A cautious equilibrium exists if and only if $\sum_{i \in N} \bar{X}_i \geq (n-1)\ell$;

ii) A dangerous equilibrium exists if and only if $\sum_{i \in N} \bar{X}_i \leq (n-1)\, h$;

iii) Cautious and dangerous equilibria coexist if and only if

$(n-1)\ell \leq \sum_{i \in N} \bar{X}_i \leq (n-1)\, h.$

Proof. Part i): By the above description of best-response strategies, a strategy profile x is a cautious equilibrium if and only if

$$
\begin{cases}
X_{-i} \leq \bar{X}_i & \text{for all } i \in N \\
\sum_j x_j = \ell
\end{cases}
\tag{6}
$$

Using the fact that $X_{-i} = \ell - x_i$ and adding up all the inequalities in (6), we have that $\sum_i \bar{X}_i \geq (n-1)\ell$. Conversely, if $\sum_i \bar{X}_i \geq (n-1)\ell$, one can always find a vector x that satisfies (6).

Part ii): Similarly, a strategy profile x is a dangerous equilibrium if and only if

$$
\begin{cases}
X_{-i} \geq \bar{X}_i & \text{for all } i \in N \\
\sum_j x_j = h
\end{cases}
\tag{7}
$$

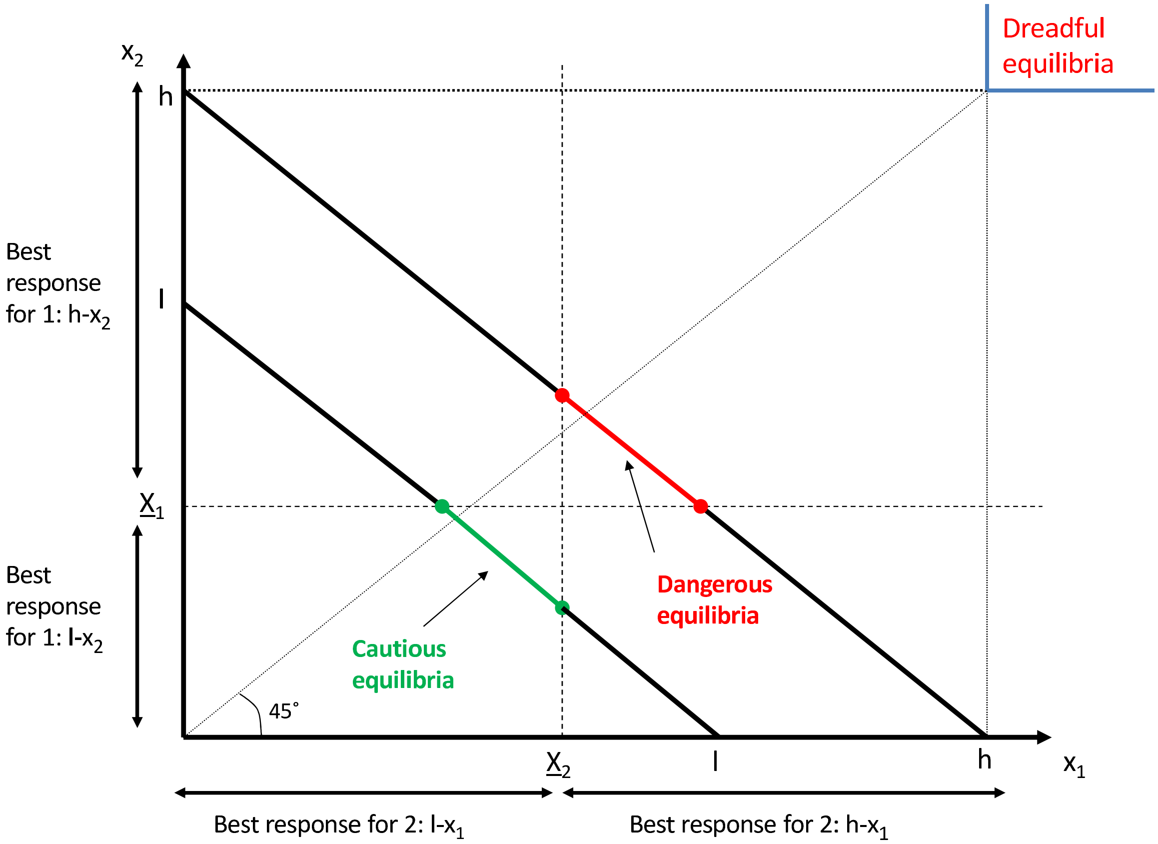

Figure 1: The two-agent case

Using the fact that $X_{-i} = h - x_i$ and adding up all the inequalities in (7), we have that $\sum_i \bar{X}_i \leq (n-1)h$. Conversely, if $\sum_i \bar{X}_i \leq (n-1)h$, one can always find a vector x which satisfies (7).

Part iii) follows trivially. □

Figure 1 illustrates the sets of equilibria in the two-agent case. These sets depend on the location of the cut-offs $\bar{X}_i$, which in turn depends on the lower bound ℓ, the probability p_h, and the agents' respective utility functions $u_i(\cdot)$.

We now discuss a few comparative statics regarding the probability p_h of the high value occurring and the intensity of the agents' risk aversion. From Proposition 1, a higher value of p_h means a lower value of the cut-off $\bar{X}_i$, owing to the fact that claiming the risky amount of resources, $h - X_{-i}$, has become relatively more tempting. As a result, the set of dangerous equilibria expands, in the sense of inclusion, whereas the set of cautious equilibria shrinks as p_h increases.

Remark 1. *Focusing on symmetric equilibria: the symmetric dangerous equilibrium exists if* $u_i\left(\ell - \frac{(n-1)h}{n}\right) \leq p_h u_i\left(\frac{h}{n}\right)$ *for all* $i \in N$*. Clearly the inequality does not hold when* $p_h = 0$ *and is true when* $p_h = 1$*. Hence there exists a* $\underline{p_i}$ *such that* $u_i\left(\ell - \frac{(n-1)h}{n}\right) = \underline{p_i} u_i\left(\frac{h}{n}\right)$*. It follows that for high values of* p_h*, i.e.* $p_h \geq \underline{p_i}$ *agent* i *does not wish to deviate from the symmetric dangerous strategy. Similarly a cautious equilibrium exists if* $u_i\left(\frac{\ell}{n}\right) \geq p_h u_i\left(h - \frac{(n-1)\ell}{n}\right)$ *for all* $i \in N$*. The inequality clearly holds at* $p_h = 0$ *and not at* $p_h = 1$*. Hence, there exists a* $\overline{p_i}$ *such that* $u_i\left(\frac{\ell}{n}\right) = \overline{p_i} u_i\left(h - \frac{(n-1)\ell}{n}\right)$ *for all* $i \in N$*. It follows that for low values of* p_h*, i.e.* $p_h \leq \underline{p_i}$ *agent* i *does not wish to deviate from the symmetric cautious strategy. Observe that if* u_i *is concave, then* $\underline{p_i} \leq \overline{p_i}$*.*[11] *Therefore, in the range* $\underline{p_i} \leq p_h \leq \overline{p_i}$*, a risk-averse agent can be part of both the symmetric cautious and the symmetric dangerous equilibria.* ◇

Similarly, if agent i becomes more risk-averse—so that the coefficient of absolute risk aversion $u_i''(\cdot)/u_i'(\cdot)$ increases, say—the cut-off $\bar{X}_i$ increases because a certain amount of resources, $\ell - X_{-i}$, is now relatively more attractive. It follows from Proposition 1 that the set of cautious equilibria expands while the set of dangerous equilibria shrinks as agents become more averse to risk, all else equal.

Example 2. *Let* $u_i(x_i) = (x_i)^\alpha$, $0 < \alpha \leq 1$, *for all* $i \in N$*. With this functional form, a symmetric dangerous equilibrium exists if* $(p_h)^{1/\alpha} \geq \left(\frac{n\ell - (n-1)h}{h}\right)$*. Similarly, a symmetric cautious equilibrium exists if* $(p_h)^{1/\alpha} \leq \left(\frac{\ell}{nh - (n-1)\ell}\right)$*.*[12] *It is noteworthy that* $(p_h)^{1/\alpha}$ *is increasing in both* p_h *and* α*. This implies that if* p_h *and* α *are such that both types of equilibria coexist, by decreasing* p_h*—and letting* α *constant—we end up with only the symmetric cautious equilibrium remaining. Similarly, by decreasing* α*—letting* p_h *constant—we eliminate the dangerous equilibrium while keeping the symmetric cautious one. This last comparative static illustrates the tension between the risk aversion effect and the coordination effect. Therefore, if risk aversion becomes very pronounced, there will be a point past which its effect will dominate the coordination effect, leading to the disappearance of dangerous equilibria.* ◇

[11] Adding $\frac{n-1}{n}(h - \ell)$ to the argument on both sides of $u_i\left(\ell - \frac{(n-1)h}{n}\right) = \underline{p_i} u_i\left(\frac{h}{n}\right)$ yields, by concavity of u_i that $u_i\left(\frac{\ell}{n}\right) > \underline{p_i} u_i\left(h - \frac{(n-1)\ell}{n}\right)$. Therefore, $\underline{p_i} \leq \overline{p_i}$.

[12] These equilibria are 'symmetric' in actions, not in payoffs.

Remark 2. *Our analysis ignores non-degenerate mixed strategy Nash equilibria. Such Nash equilibria are salient in the standard NDG –see for instance Malueg (2010) for a very nice treatment of the mixed-strategy Nash equilibria case in two players NDG. The stochastic NDG does not escape this conclusion. For instance, any randomization over dreadful equilibria would be a mixed-strategy Nash equilibria. There also exist mixed-strategy equilibria where agents randomize only on the cautious and dangerous strategies.*[13] *While the characterization of mixed-strategy equilibria is an interesting problem, it is beyond the scope of this paper.*

3.2 Efficiency

We now assess the efficiency properties of each type of equilibria. It turns out that cautious equilibria are not only Pareto-efficient, they are also strong Nash equilibria. The following proposition determines whether dreadful and cautious equilibria are strong in this sense.

Proposition 2. *Cautious equilibria are strong, but dreadful equilibria are not.*

Proof. From a dreadful equilibrium, any group deviation leading to a cautious or a dangerous strategy profile, be it a deviation by the entire set of players, obviously brings a higher payoff to all agents in the coalition. Hence, dreadful equilibria are not strong.

The proof that cautious equilibria are strong proceeds by contradiction. Let $x \in \mathbb{R}^n_+$ be a cautious equilibrium, and suppose there exists another strategy profile x' and a coalition $T \subseteq N$ such that $x'_k = x_k$ for all $k \notin T$, $v_i(x') > v_i(x)$ for some $i \in T$, and $v_j(x') \geq v_j(x)$ for all $j \in T$. Because the utility functions u_j's are increasing, it must be the case that $\sum_{j \in T} x'_j > \sum_{j \in T} x_j$ and $x'_j \geq x_j$ for all $j \in T$. Now, consider an agent $j \in T$ such that $X'_{-j} > X_{-j}$. For this agent, demanding $x'_j = \ell - X'_{-j}$ or less leads to a lower payoff than before; her best response must be $x'_j = h - X'_{-j}$. We then have that $v_j(x'_j, X'_{-j}) = v_j(h - X'_{-j}, X'_{-j}) < v_j(h - X_{-j}, X_{-j}) \leq v_j(x)$, where the last inequality holds because x is a Nash equilibrium. Agent j is thus worse off under x' than under x, which contradicts the initial assertion. $\square$

[13]For instance, let $n = 3$, $\ell = 6$, $h = 12$, $p_h = 0.5$ and $u_i(x) = (x_i)^{\frac{1}{4}}$. Under such a parameter constellation, both a symmetric cautious and dangerous equilibrium exist. It can be shown that there is a mixed strategy equilibrium in which each agent i randomize on $x_i = 4$ with probability around 0.56, and with the remaining mass on $x_i = 2$.

This proposition entails that all cautious equilibria are Pareto efficient. Furthermore, any cautious equilibrium Pareto-dominates all dreadful ones. The status of dangerous equilibria is not so clear-cut, however. The following result shows that a cautious equilibrium Pareto-dominates all dangerous equilibria that can be reached from it while increasing every agent's claim.

Proposition 3. *Let the strategy profile x be a dangerous equilibrium. Any cautious equilibrium x' such that, for some subset $T \subseteq N$,*

$$\begin{array}{ll} x'_i = x_i - \alpha_i & \text{for all } i \in T, \text{ and} \\ x'_i = x_i & \text{for all } i \notin T, \end{array} \tag{8}$$

with $\alpha_i \geq 0$ for all $i \in T$ and $\sum_i \alpha_i = h - \ell$, Pareto-dominates x.

Proof. Suppose a dangerous equilibrium x and a cautious equilibrium x' verifying condition (8). For all $i \in T$, we have that

$$\begin{aligned} u_i(x'_i) &\geq p_h u_i(x'_i + h - \ell) \\ &= p_h u_i(x_i + \sum_{j \neq i} \alpha_j) \\ &> p_h u_i(x_i). \end{aligned}$$

The first inequality holds because x' is itself a Nash equilibrium. The second (strict) inequality follows from the fact that $\sum_{j \neq i} \alpha_j > 0$, for $\sum_{j \neq i} \alpha_j = 0$ would mean that x is not a Nash equilibrium (since the cautious equilibrium x' could then be reached from it through a unilateral move by agent i). $\square$

An important consequence of Proposition 3 is the following: if dangerous and cautious equilibria coexist, not only a symmetric cautious is Pareto efficient and strong, but then the symmetric dangerous equilibrium is always Pareto inefficient.

4 Experimental Design

The experiment implements the stochastic NDG using a between-subjects design. The different treatments vary the probability p_h that the threshold is high. The following two parameters are constant across all treatments: the high threshold is $h = 24$ while the low threshold is $\ell = 18$. These values are common knowledge among participants,

Table 1: Experimental Design

Treatment	Probability p_h	Subjects[a]	Sessions
T03	0.3	36 (6)	3
T05	0.5	36 (6)	3
T07	0.7	72 (12)	6
T09	0.9	36 (6)	3
T099	0.99	36 (6)	3

Sessions were run at the labs of the University of Bern (first wave: 108 subjects, treatments T03-T05-T07) and NYU Abu Dhabi (second wave: 108 subjects, treatments T07-T09-T099). (a) Number of independent observations (matching groups) in parentheses.

only their probabilities of occurrence vary across treatments. Probabilities of occurrence are also common knowledge among participants within a given treatment. Table 1 summarizes the experimental design. Each subject participated in only one treatment. We explain below the procedures and provide details on the implementation of the different treatments.

The first wave of data collection took place at the experimental laboratory of the University of Bern (Spring 2014) with a total of 108 participants. For the first wave, we implemented three sessions (12 subjects each) for each of the first three treatments T03, T05 and T07. The second wave of data collection took place at SSEL, the laboratory of NYU Abu Dhabi (Fall 2018). We implemented there three sessions (12 subjects each) for each of the last three treatments T07, T09 and T099. The doubling of T07 at NYU Abu Dhabi is meant to provide a benchmark for replication of the results initially obtained in Bern. The results on T07 regarding the main variables of interest cannot be statistically distinguished across the two locations.[14] Since there are no differences between the two locations on this treatment, we pool the data across locations. In addition, the replication of the results on T07 allows us to make meaningful comparisons between the new treatments T09 and T099 with the other treatments.

[14]For instance there are no statistically significant differences between (average) individual demands or group demands (p-value= 0.75). This is also confirmed by various random effects regressions using a location dummy variable (along with some other co-variates) with (i) individual demands x_i as the explanatory variable, (ii) $\sum_i x_i$ in groups as the explanatory variable, $x_i = 6$ or $x_i = 8$ as the explanatory variables. In all regressions, the location dummy variable has a non-statistically significant effect, thereby showing that there are no statistically significant differences in T07 across the two locations.

At each location, each session lasted around 60 minutes and each involved different participants. In Bern, participants earned an average of 32 CHF for their participation (including a 5 CHF show-up fee)—roughly \$31US. In Abu Dhabi, participants earned an average of 110 AED for their participation (including a 30 AED show-up fee) —roughly \$29US.[15]

At the start of a session subjects are informed that the experiment will be composed of several parts, but are not given any information regarding these until they actually take place. We distributed the instructions for Part 1 of the respective treatment. Once the participants finished reading the instructions, a member of the experimenter team provided a verbal summary. There is no framing and the wording is neutral—see attached instructions in the online appendix. Participants were also asked to answer a set of control questions which had to be answered correctly before the experiment could proceed. The stochastic NDG was played ten times, and we therefore say that there were ten periods. Each session is composed of twelve subjects who are divided into two silos (blocks) of six. Subjects in different silos sit in the same room but never interact with one another when playing the stochastic NDG. At the beginning of each period, participants in each silo are assigned randomly into *groups* of three. Groups are reshuffled each period within each silo and identities are unknown throughout to minimize reputation effects. Given the silos' construction, we have six independent observations per treatment (two per session). In each period, groups play the stochastic NDG given the probability p_h that prevails in the session. In addition, in each period, before submitting a demand, participants give an estimate of the sum of the demands that the other two in their group will ask for. We interpret this as the belief that participants form regarding the behavior of their group members. This belief elicitation is incentivized.[16] Subjects are told in the instructions and by the experimenter that, for Part 1, they will be paid three randomly chosen periods out of the ten periods played (belief and payoff from the stochastic NDG combined). With this, we aim at forcing subjects to be focused on their choices in each period, as well as reducing hedging and repeated-game effects. The random selection of the payoff-relevant periods is made at

[15] Participants payments (at the end of the experiment) in Bern were rounded up to the next higher 0.5 CHF, the standard rounding at the University of Bern. Participants payments at NYU Abu Dhabi are rounded up to the nearest integer AED (no cents are carried out), the standard rounding procedure at the SSEL lab.

[16] If a participant correctly estimates the demand of the others in his group, he gets 1.5 extra experimental dollars. If his estimation deviates by one, he receives only 1 experimental dollar. If his estimation differs by 2 points, he gets 0.5 experimental dollar. If it differs by more, he/she gets nothing.

the end of the experiment.

When moving to the next part, subjects are informed that out of Parts 2 and 3, only one will be randomly chosen to be payoff-relevant. Parts 2 and 3 each makes use of some multiple-price list. In Part 2, we elicit subjects' risk preferences using a standard multiple price list technique (Holt and Laury, 2002). In Part 3, subjects faced a tailor-made multiple-price list to evaluate their propensity to play symmetric cautious equilibria. Subjects have a list of ten decisions to make, each decision involving the choice between two lotteries—A and B—where A always brings a certain amount of 6 and B brings 12 with some probability q. The probability to obtain 12 in decision B is equal to $q = 0.1$ for decision 1, $q = 0.2$ for decision 2,... and $q = 1$ for decision 10. We simply record the decision at which a subject switches between lottery A and B.The number of successive choices is indicative of the attitude towards risks of subjects: the risk-averse switch between lotteries A and B happens after the fifth decision (the fifth decision presents a decision between getting 6 for sure, or 12 with probability 0.5). This task also allows us to highlight the likelihood of symmetric dangerous and cautious equilibria per treatment. Notice that an agent switches at the probability where having 12 with uncertainty brings a higher expected payoff than having 6 with certainty. This coincides with the probability at which an agent with a belief that the others collectively play 12 switches away from the cautious play.

5 Experimental Results

5.1 From Theory to Evidence

Our theoretical results reveal that groups of risk-averse individuals may engage in risk-taking behavior in equilibrium. This adds a new layer to the coordination problem: not only must players coordinate "within" the set of equilibria whose demands sum to a given level, say 18, but they must also coordinate *between* sets of equilibria—those summing to 18 and those summing to 24—when dangerous and cautious equilibria coexist. In practice, "within" coordination failures may not be so serious because agents often focus on symmetric share profiles where each asks for an equal split of the targeted stock value. However, how agents solve the "between" coordination problem is far from clear, which is why we turn to an experimental test. We shall investigate the following three hypotheses:

1) *Cautious and dangerous equilibria can coexist even though all agents are risk-averse* (consistent with Proposition 1): in terms of the experiment this implies that we should observe both cautious and dangerous behavior inside a silo, irrespective of the risk aversion of subjects (proxied by the probability at which they switch in Part 3). We expect this feature of behavior to be more salient for intermediate values of p_h where cautious and dangerous equilibria are more likely to coexist within a silo (T05 and T07).

2) *Cautious equilibria should occur more often for low values of p_h and dangerous equilibria more often at higher values of p_h* (in accordance with Remark 1). We thus expect to find a higher rate of cautious equilibria in the treatments with low p_h, i.e. T03 and T05, than in their counterpart treatments with higher p_h (and conversely for dangerous equilibria).

3) *Coordination becomes more difficult when coexistence of equilibria is more likely* (consistent with an increase in "between"-coordination failures when both equilibria exist). Hence, we should observe equilibrium play (both cautious and dangerous) less often in treatments with intermediate values of p_h, i.e. T07 and to some extent T05, where coexistence of these equilibria is more likely. This coordination problem should disappear for lower values of p_h, where only cautious equilibria typically exist, and for higher values of p_h, where only dangerous equilibria typically exist.

From now on, we will call a demand profile x *consistent with a Nash equilibrium* whenever demands sum to 18 or 24, and this for all of our treatments. Likewise, we will talk about a *symmetric individual Nash strategy* for subject i if his demand x_i is either 6 or 8, and this for any of our treatments. We often refer to the cautious strategy for subject i when $x_i = 6$, and to the dangerous strategy for subject i when $x_i = 8$. The focus of our analysis will be on symmetric Nash equilibria.

5.2 Preliminary Remarks

We give here an overview of important trends coming out of our experiment. This will help us forming some first intuitions regarding the three central results of the experiment.

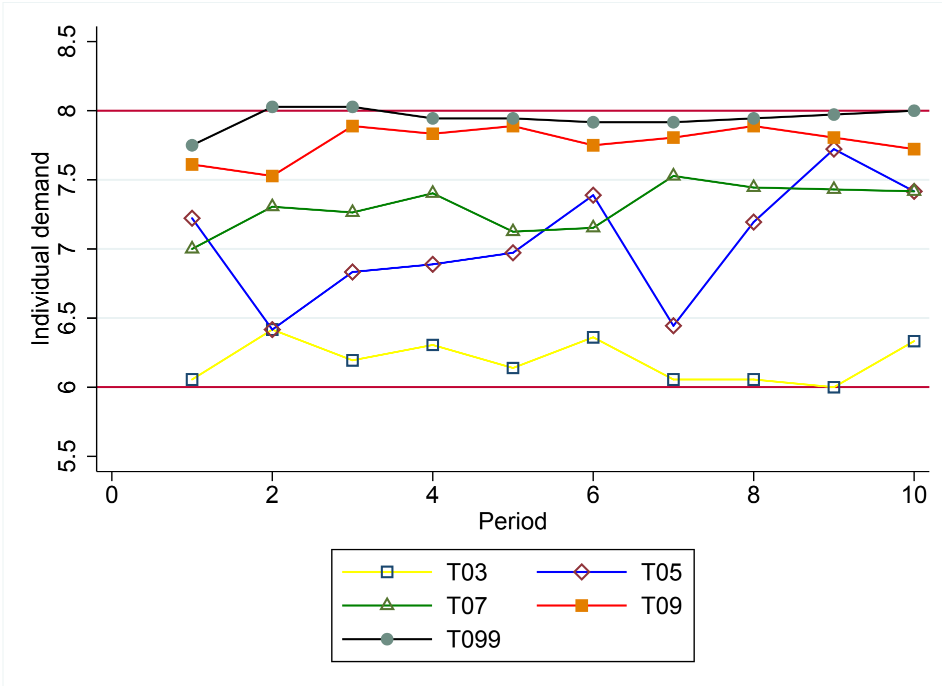

Figure 2: Average individual demand by period

Average demands First, we observe that behavior differs across treatments, both at the individual and group levels. Figure 2 shows average individual demands over time by treatments.[17] Treatments T03, T09 and T099 present (relatively) stable individual demand over the 10 periods (around 6 and 8) while demand in T07 is clearly increasing towards 8 and T05 stands in the middle with a possible convergence toward 8.

However, average demands are not necessarily the best measure of behavior to consider since they are silent regarding the type of strategy chosen by participants (as well as equilibrium versus non-equilibrium behavior). Indeed, Result 1 will confirm that both types of strategies (cautious and dangerous) coexist in the data, especially in the treatment T07.

Nash equilibria Across all treatments, almost half of the outcomes are Nash equilibria (52.3%). The rate of Nash equilibria (and their type, cautious/dangerous) clearly differ across treatments. Importantly, the vast majority of these Nash equilibria are symmetric. We will thus focus on these symmetric equilibria for the rest of the analy-

[17]The two horizontal lines at 8 and at 6 stand respectively for the dangerous and cautious symmetric demands.

Treatment	Cautious NE	Dangerous NE	Coord. failure rate = $100 - CNE - DNE$
T03	65%	5%	30%
T05	37.5%	11.7%	50.8%
T07	10%	18.3%	72.7%
T09	0.8%	58.3%	40.9%
T099	0%	79.1%	21.9%

Table 2: Equilibria Rates by Treatments

sis.

Table 2 hints at two important features of our results. We can see that two types of coordination failures are impacted by the probability p_h: (i) as we move across treatments, groups focus less and less on the (Pareto-dominating) cautious equilibrium (Result 2); (ii) the impact on equilibrium play is non-linear and U-shaped (Result 3).

Risk aversion and predicted play. Recall that in Part 3 the proportion of players who *did not* switch at a given probability q is willing to play a symmetric cautious equilibrium if they expect others to do so. Furthermore, we can also infer a lower bound of the proportion of players willing to play the symmetric dangerous strategy: when an agent i switches at a probability q or below we know that $u_i(6) < q \cdot u_i(12)$. This condition, coupled with the concavity of $u_i(.)$, implies that $u_i(2) < q \cdot u_i(8)$ holds when an agent i switches at q or below. Notice that this last condition guarantees that agent i would play a symmetric dangerous strategy if she expects others to do so. In other words, the proportion of players switching at q in Part 3 *is willing* to play a symmetric dangerous strategy and *is not willing* to play a symmetric cautious strategy at any probability $\gamma \geq q$.

This reasoning is illustrated in Figure 3, relating the probability at which subjects switched in Part 3 and their observed cautious/dangerous play in the stochastic NDG (averaged per silo). The first figure relates the proportion of subjects who did not switch at any given probability—the proportion playing cautious in a silo—while the neighboring figure relates the proportion of subjects who did switch—the proportion playing dangerous. As predicted, both quantities are quite closely related.[18]

[18] They are a bit different because subjects have more strategies at their disposal in the stochastic NDG (and may thus aim at different equilibria than the symmetric ones).

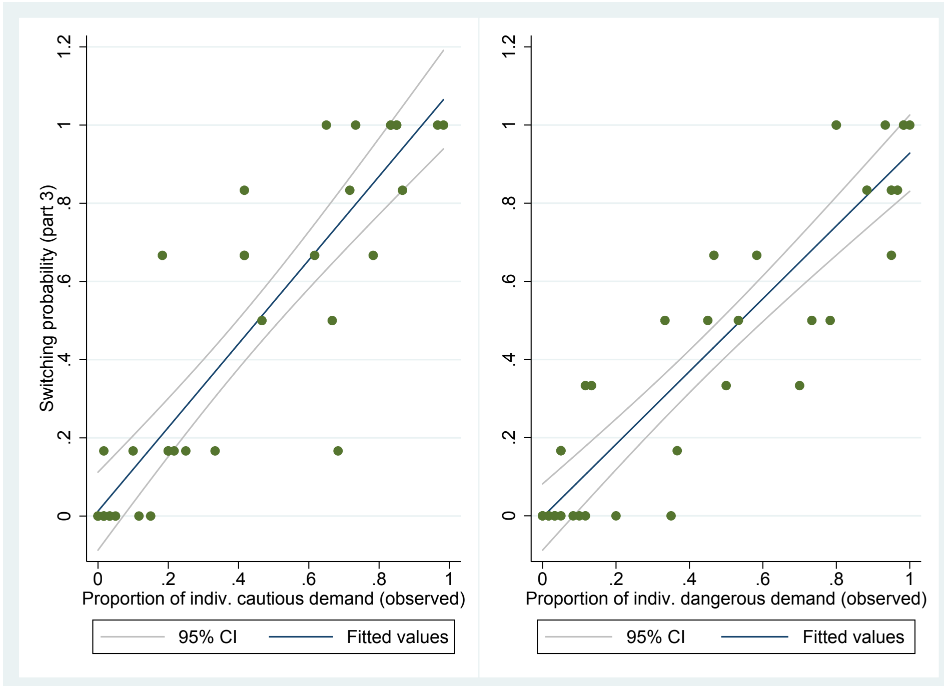

Figure 3: Probability switching (Part 3) and type of equilibrium play

5.3 Experimental Results

We now turn to the main findings of the experiment, which we present in the following four results below.

Result 1: Cautious and dangerous equilibria coexist, irrespective of agents risk-aversion. We first show that both cautious and dangerous play coexist. We next show that this is not related to risk-aversion.

Cautious and Dangerous strategies coexistence is maximal for $p_h = 0.7$. In order to highlight how the treatment probability impacts the type of equilibrium play, we first compute a variable "type of equilibrium play" equal to the proportion of subjects in a silo playing the cautious demand (6) minus the proportion playing the dangerous demand (8), averaged across all periods per silo. This variable is thus equal to -1 when all play dangerous in a silo, to 1 when all play cautious, and to 0 when coexistence is maximal (50% of a silo across all periods play cautious and 50% play dangerous).

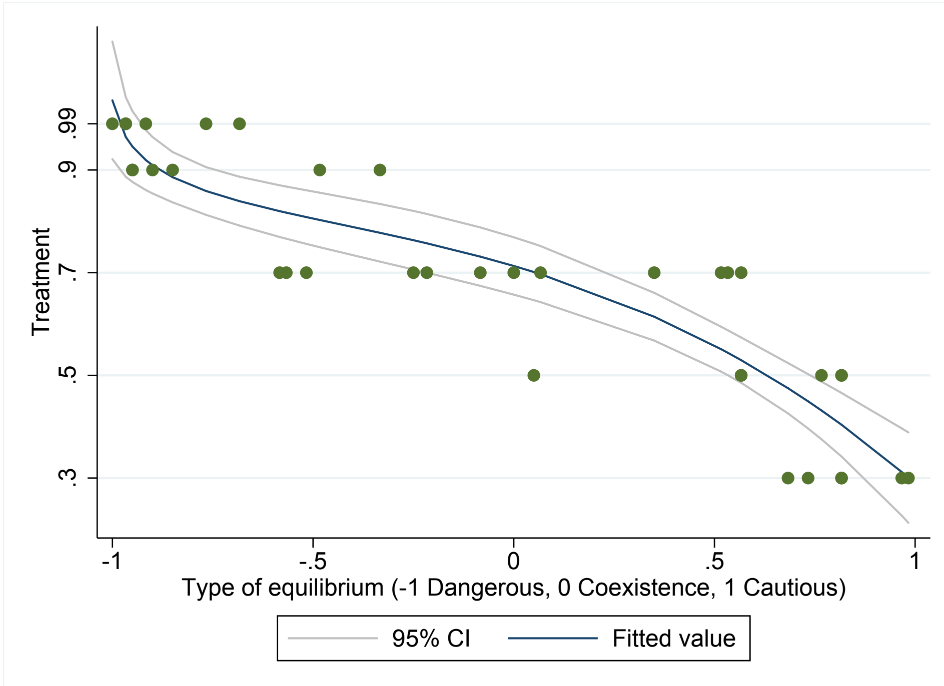

Figure 4: Type of Equilibrium play and Treatment

Figure 4 shows clearly that the dangerous play dominates for T099 and T09 while cautious behavior is dominant for T03 (and present in T05). An interesting observation is that coexistence is maximal when $p_h = 0.7$: on average, in T07, subjects were equally likely to play cautious than dangerous.[19] This pattern is strikingly similar when we use the "predicted play"—from Part 3—for computing the "predicted type of equilibria" in each silo, instead of the actual stochastic NDG play (see Figure 11 in the appendix).

Equilibrium play is uncorrelated with risk aversion. The second observation is that risk preferences are not statistically related to the individual strategy chosen by subjects in our sample. This point is consistent with our first theoretical prediction: Despite agents being risk-averse, cautious and dangerous strategies are played when both strategy are more likely to coexist.

[19]Figure 10, in the appendix, shows a Kernel density estimation to analyze the distribution of individual demands. We observe a clear bimodal distribution in demands when $p_h = 0.7$, confirming the trend observed in the task described above: agents focus on playing both 6 or 8 in this treatment. We observe a strong shift at the individual level toward 6 when $p_h = 0.5$ (with a little bump around "8") and $p_h = 0.3$ and strong shift toward 8 when $p_h = 0.9$ and $p_h = 0.99$.

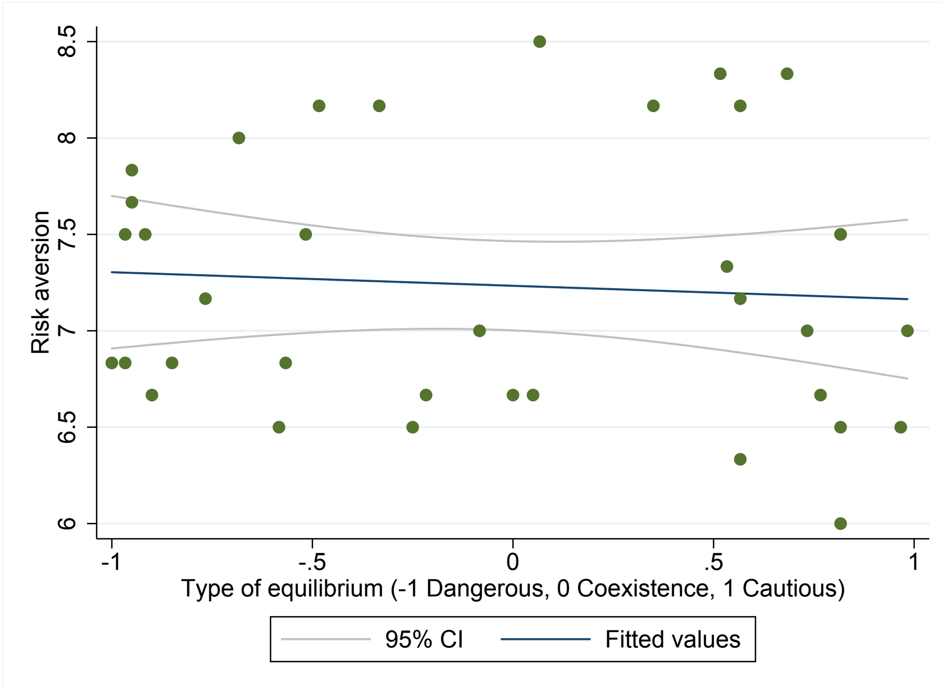

Figure 5: Type of equilibrium and risk aversion (average per silo)

We observe in Figure 5 an apparent lack of relationship between type of equilibrium play and risk preferences (averaged per silo). This observation is supported by a random-effect regression with the number of safe choices as the unique explanatory variable (p-value = 0.997).[20] Hence, if risk aversion plays a role for determining the existence of both types of equilibria, it does not impact the choice of a dangerous or a cautious strategy when both coexist.

Result 2: Individual and group cautious (resp. dangerous) play is decreasing (resp. increasing) in p_h. Figure 6 below shows that individual cautious play (averaged at the silo level) is very high when $p_h = 0.3$ and decreases sharply as p_h increases. In contrast, individual dangerous play increases as p_h increases.[21] A set of Jonckheere-Terpstra tests confirm these observations. Cautious play is clearly decreasing with p_h (p-value< 0.001 at individual and group level) and dangerous play increasing (p-value< 0.001 at individual and group level).

[20]As shown in Table (3) in the appendix, this result is robust to the inclusion of beliefs as well as a set of treatment and periods fixed-effects.

[21]Figure 12, in the appendix, shows that these patterns remain true at the group level.

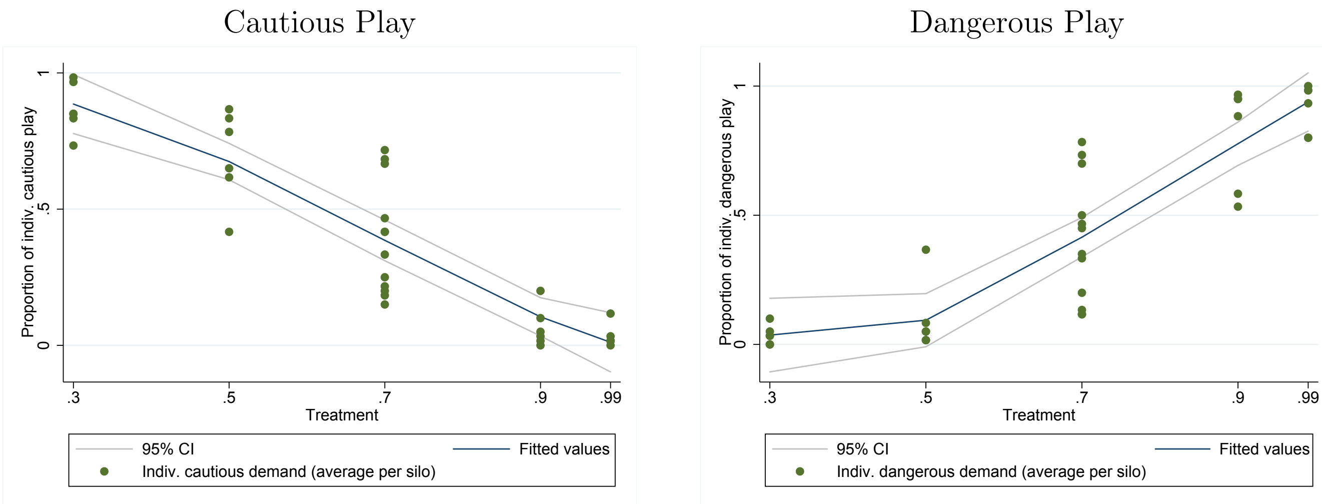

Figure 6: Equilibrium play and treatment (per silo)

Result 3: Coordination on any equilibrium becomes more difficult when coexistence of equilibria is more likely. The main observation here is that agents' actions are less and less in line with an equilibrium play when the coexistence of equilibria becomes more likely.[22]

Figure 14 (in the appendix) shows that the rate of equilibrium play (at the individual and group level) is indeed related in a non-linear way with the probability (the U-shaped relation is confirmed in a random effects regression, see Table (4) in the appendix). Coordination on any equilibrium is minimal at T07. We argue that coordination failure on equilibrium behavior is driven by coexistence. An important aspect of equilibrium versus non-equilibrium behavior in the stochastic NDG is the extent to which subjects fail to precisely coordinate on one of the two symmetric equilibrium demands.

Given the anonymity conditions in which the experiment takes place, and despite the possible learning at play because of repeated interactions, having symmetric (equilibrium) demand profiles seems focal. This is however not informative regarding the extent to which subjects may fail to fully coordinate on one of the two of the symmetric dangerous and cautious demand profiles when they coexist, what we call "between"-equilibria coordination failure.

Figure 7 highlights that, indeed, it is when coexistence is most likely that the equi-

[22] As mentioned above, this trend should disappear for very low value of p_h, when the dangerous equilibrium becomes very unlikely, and for very high value of p_h, when the cautious equilibrium disappears.

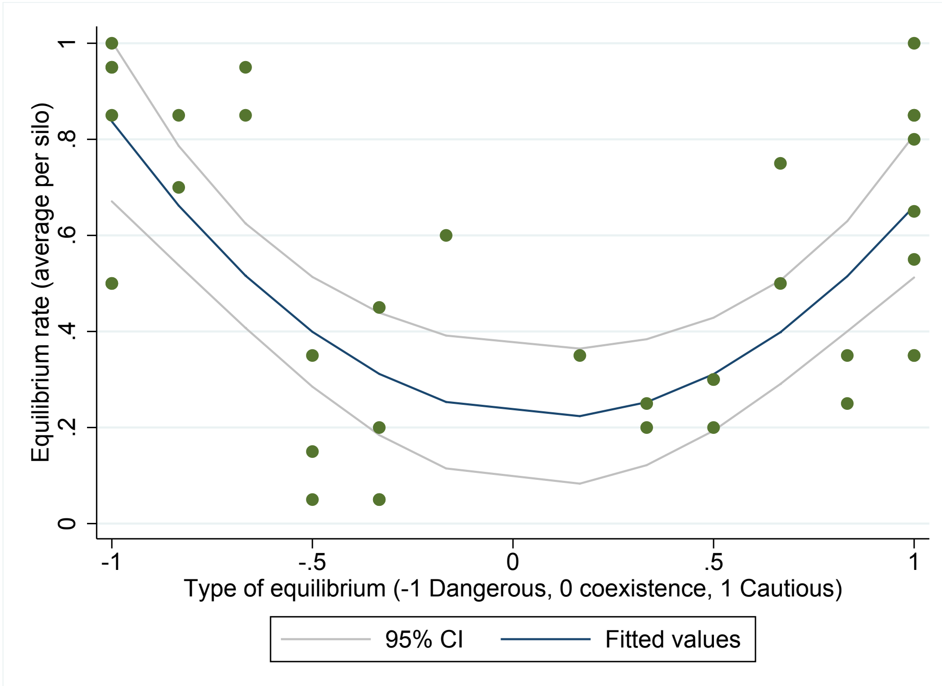

Figure 7: Coexistence of equilibria and equilibrium play (averaged per silo)

librium rate is at its lowest. When either the cautious or the dangerous outcomes are more focal, equilibrium play increases sharply.

Interestingly this pattern stands true for other type of coordination failure. This is an interesting result that came about from the experiment, which was not expected a priori. We document this with our last result.

Result 4: Overshooting increases when coexistence of equilibria is more likely. Let us briefly investigate collective claims beyond either the high or low value of the resource. We say (i) that a group is *overshooting* in a given period if its (group) demand exceeds 24—recall that subjects in the group each gets 0 in this case—. We notice clear differences across treatments (see Figure (15) in the appendix): overshooting is at its highest (around 10% of individual play) for T05 and T07. Interestingly, this difference seems to be related to coexistence: Figure (8) highlights that overshooting behavior (at the individual and group level) is higher when coexistence is more likely than when dangerous or cautious are more likely (i.e. we here use the predicted play from Part 3). This inverted U-shape relation is confirmed in a regression with random effects (see Table (5) in the appendix).

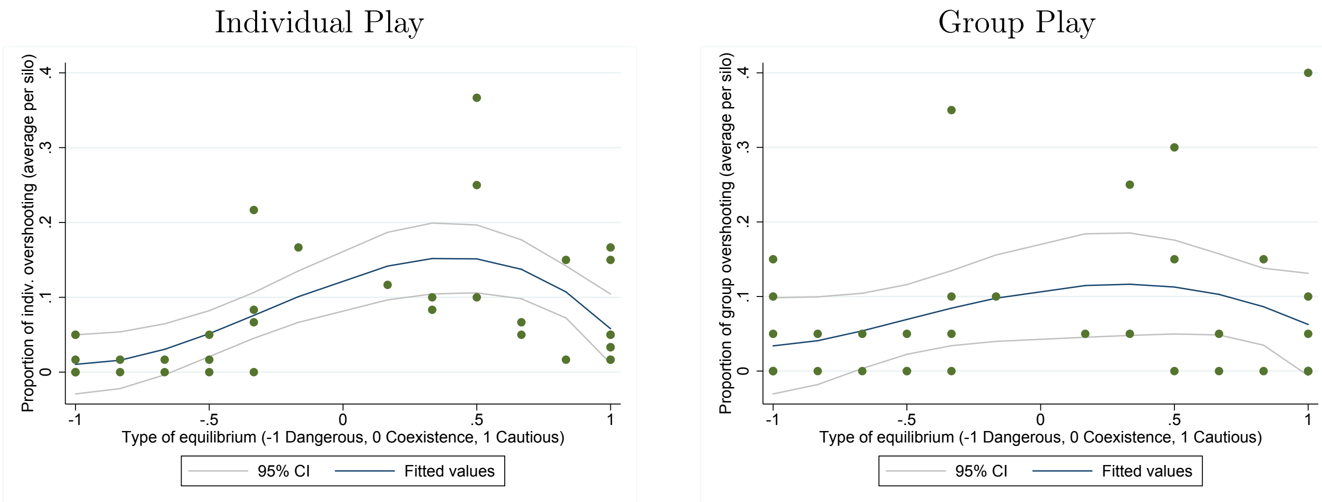

Figure 8: Overshooting and coexistence (averaged per silo)

Finally, the impact of coexistence on coordination issues is reflected in the average payoff of subjects: Figure (9) clearly highlights that the average payoff of players *decreases* when coexistence is most likely (i.e. for intermediate values of p_h).

Remark 3. *A conclusion coming out of Results 3 and 4 is that subjects experience difficulty in coordinating between the two sets of equilibria for intermediate values of* p_h*, in particular for T07. Notice however that subjects play the stochastic NDG only ten rounds in the experiment. The between-coordination problem witnessed for T07 may be resolved more effectively with a longer time horizon –and as such, it is not entirely clear whether the observed behavior for intermediate values of* p_h *is "asymptotic". It would be interesting to see if the dynamic of play changes over different time horizons.*[23]

6 Concluding Remarks

Our experiment raises several interesting questions for future research. First, subjects played the stochastic NDG for ten rounds. It is important to figure out wether the coordination failures that become salient for intermediate values of p_h survive under different time horizons. Indeed, solving the between-set of equilibrium coordination problem may be possible when the time horizon faced by subjects is longer than ten rounds. We should be clear here that a longer time horizon means additional repetitions

[23]We thank an anonymous referee for this observation.

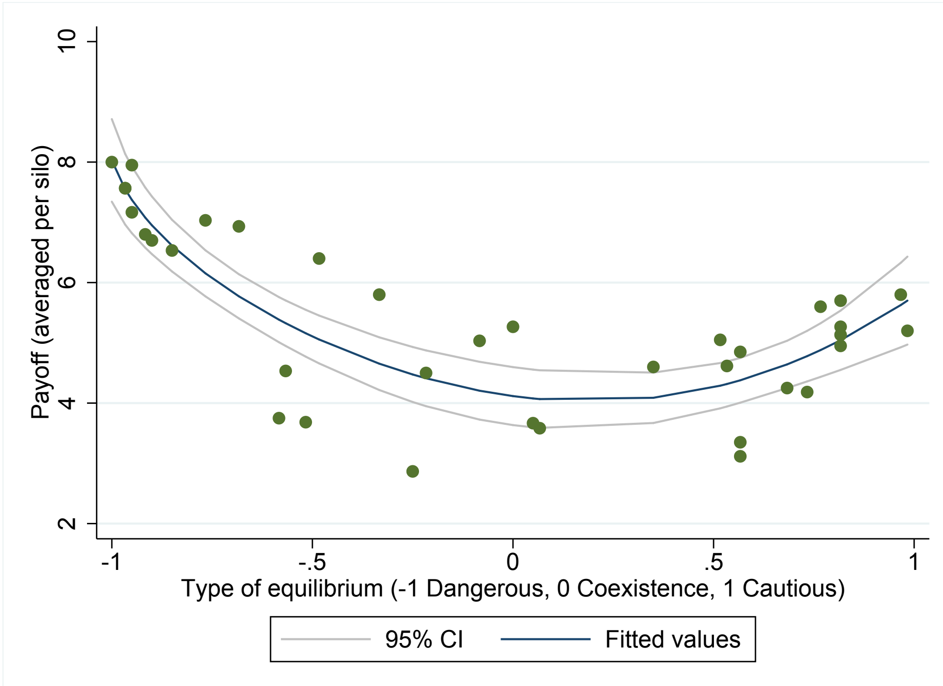

Figure 9: Realized payoff and coexistence (averaged per silo)

of the one-shot stochastic NDG. It could be that the behavior observed in T07 is not "asymptotic" because solving the "between" problem would require more repetitions. Next, it would be interesting to see how subjects' play is affected to shocks. Our current design is between-subjects and subjects get to experience only one bimodal distribution. Studying an extension of this paper with a within-subject design in which subjects experience shifts in the probabilities attached to the bimodal distribution would shed light on how subjects react to changes in the uncertainty faced in their environment. Along the same line, we could also confront subjects to a shift from a situation with certainty (e.g. where the high threshold occurs for sure) to a situation where both thresholds become likely. It is possible that different risk attitudes play a role in subjects' reaction and adaptation to the change in their environment

On the policy side, the existence of uncertain thresholds on the consumption of a common-pool resource raises several issues. An important one is whether to adopt or not some precautionary measures. The feasibility and social desirability of such actions have been widely debated in policy circles and remain an active research topic (see, e.g., Wiener 2010, Barrieu and Sinclair-Desgagné 2006, and the references therein). In the present context, taking a precautionary stance would mean to avoid claiming collectively more than the lowest possible threshold. Contrary to the current literature, which assumes that this outcome can be implemented by a benevolent planner or representative agent with the proper kind of risk or ambiguity aversion (see, e.g., Martimort and Sand-Zantman, 2016, for a recent contribution to the climate change problem), Proposition 1 and our experimental results suggest that this outcome might well be achieved in a decentralized fashion through reaching a 'cautious' equilibrium.

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A Complementary Experimental Results

A.1 Result 1

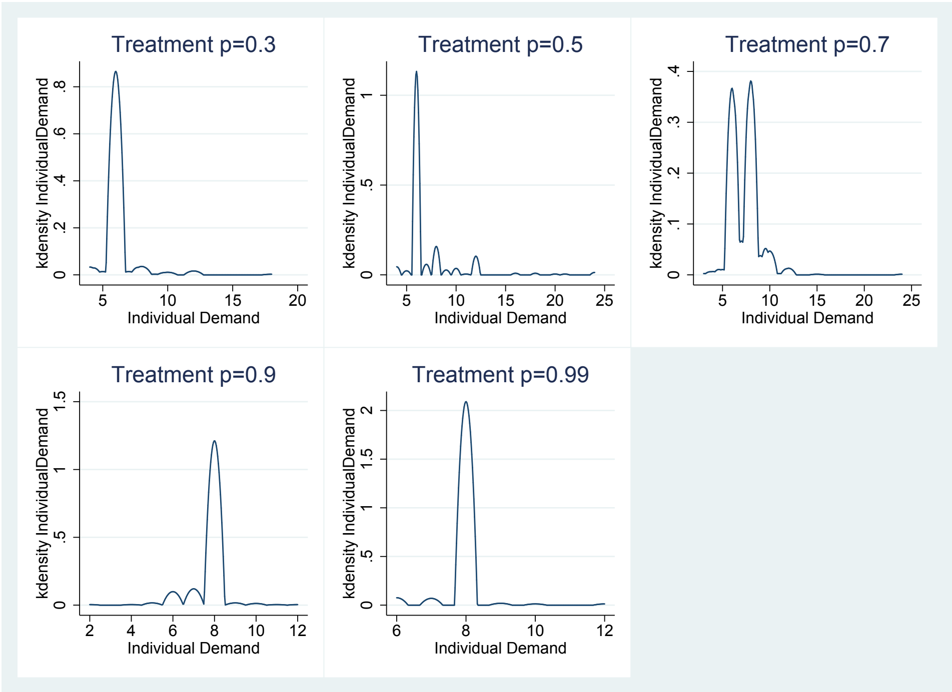

Figure 10: Average individual demand by treatment

Table 3: Risk aversion and individual demand

	(1)
	Individual Demand
Belief	0.091***
	(0.026)
Risk aversion	-0.025
	(0.056)
Probability	0.008***
	(0.001)
N	2160
Period FE	Yes

Notes: The regression includes random effects. Standard errors (clustered at the silo level) in parentheses. * Significant at the 10 percent level; ** Significant at the 5 percent level.

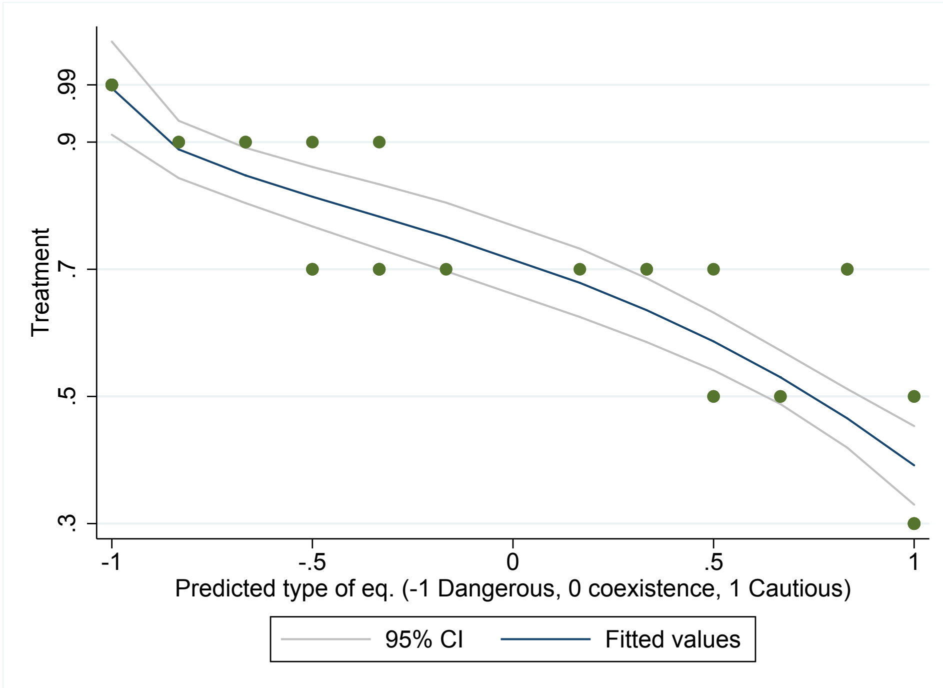

Figure 11: Predicted equilibrium play (Task 3) by treatment

A.2 Result 2

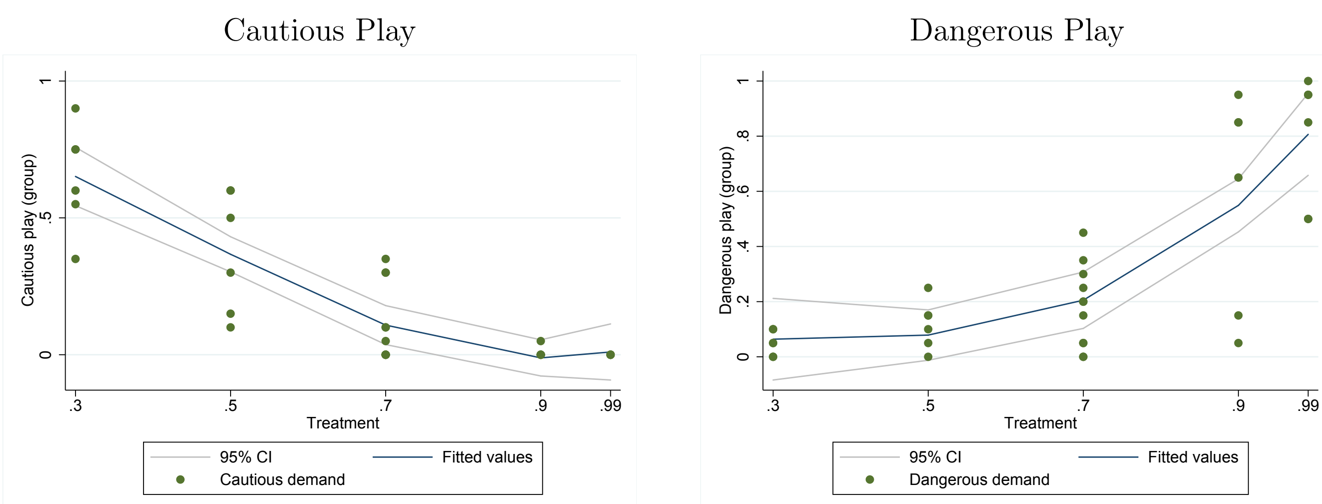

Figure 12: Cautious and Dangerous equilibrium play at the group level

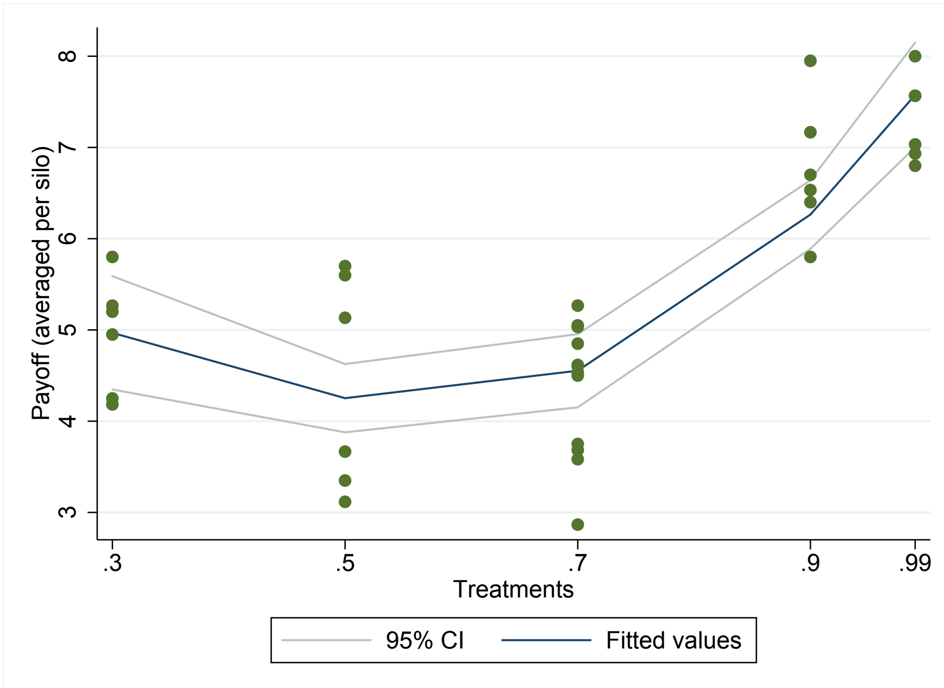

Figure 13: Realized payoff and Treatment (averaged per silo)

A.3 Result 3

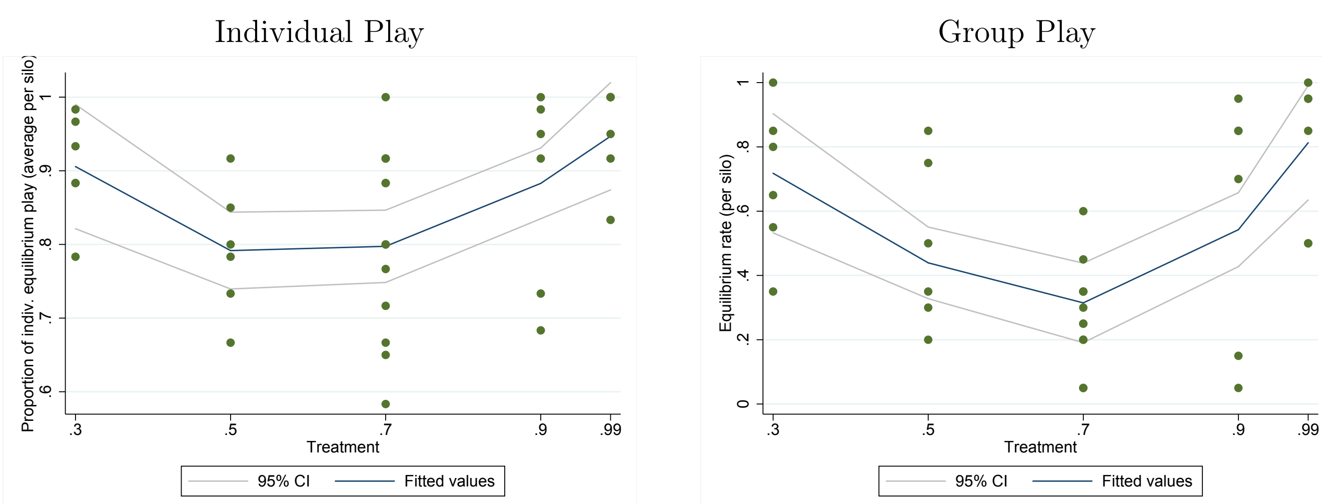

Figure 14: Equilibrium play per treatment (individual and group level)

Table 4: Equilibrium play and treatments

	(1) Equilibrium play	(2) Equilibrium play
Belief	-0.004	-0.005
	(0.003)	(0.005)
Probability	-0.059***	-0.178***
	(0.000)	(0.001)
Probability^2	0.001***	0.002***
	(0.000)	(0.000)
Period FE	Yes	Yes
Subject FE	Yes	Yes
N	2160	2160

Notes: The regression all include random effects. Standard errors (clustered at the silo level) in parentheses. * Significant at the 10 percent level; ** Significant at the 5 percent level.

A.4 Result 4

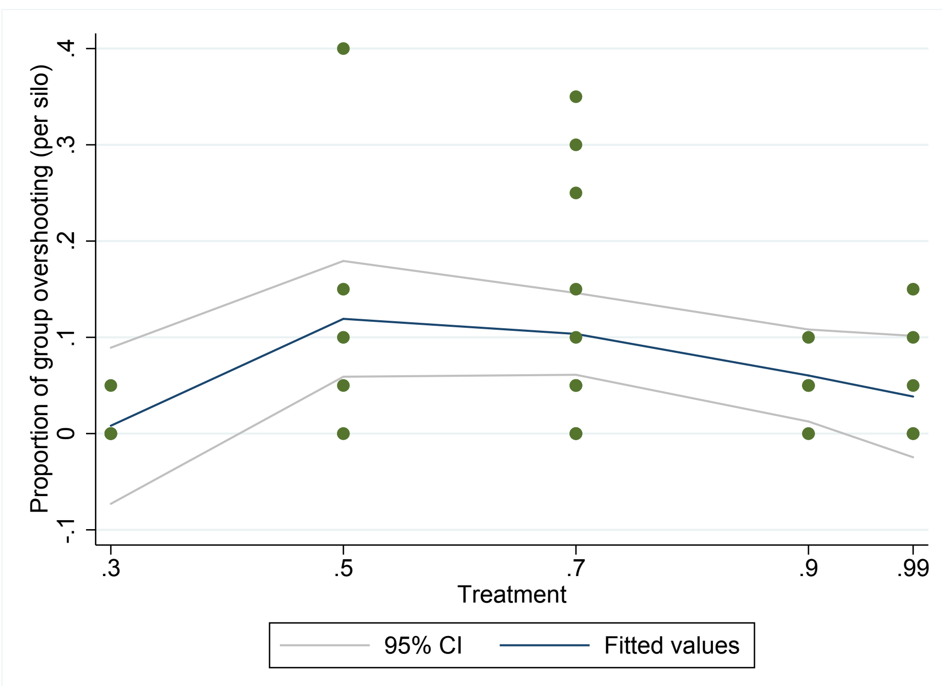

Figure 15: Overshooting across Treatments

Table 5: Overshooting and Treatments

	(1) Overshooting	(2) Overshooting
Probability	-0.059***	-0.178***
	(0.000)	(0.001)
Probability^2	0.001***	0.002***
	(0.000)	(0.000)
N	2160	2160
R^2		
pseudo R^2		

Notes: The regressions all include random effects. Standard errors (clustered at the silo level) in parentheses. * Significant at the 10 percent level; ** Significant at the 5 percent level.