Environmental uncertainty in commons dilemmas: a survey of experimental research

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Abstract: I conducted a systematic review of experimental resource dilemma studies that manipulated environmental uncertainty. I classify the collected studies according to whether the incentives reflected a coordination or a cooperation problem. I provide, for each type of incentive, a general overview of the strategic setting and its adaptation to the experimental paradigm. I find that, regardless of the type of incentives, environmental uncertainty has an efficiency-diminishing effect in most of the experimental settings. I also present and discuss a selective set of experiments mimicking the climate change problem, in which the proposed incentives combine elements from coordination and cooperation problems. I conclude with a general discussion of the findings about how different sources of environmental uncertainty affect efficiency in collective action problems, paying special attention to climate change issues.

1. Introduction

The appropriation of a common pool resource (CPR hereafter) is subject to sub-optimal outcomes given the rivalry and non-excludability of the good. When the environment is stable, and users of the common good are well informed about it, the only source of uncertainty faced in the collective management of the resource is social: subjects reason about what they would do, contingent on what they expect others would do.

A fluctuating environment brings an additional problem to CPR management. Imperfect information about the current state of the environment (e.g. stock sizes, growth rates, boundaries of the shared resource) adds one layer of complexity to the decision: subjects reason about what they would do, contingent on what they expect others would do, *in every* potential state of the environment. Coordination mechanisms, including communication and norm-crafting (Ostrom et al. 1994; Ostrom 2006), are not very likely to reduce uncertainty in this scenario: to align what individuals think others would do, such a mechanism will need first to provide credible signals about the likeliest state of the environment.

Consider for instance on the difficulties to reach agreements for the reduction of CO_2 emissions: parties can be reluctant to cooperate because they expect others to not cooperate (social uncertainty), because they are not convinced that the emissions reduction will have an effect given the deterioration rate of the environmental conditions (environmental uncertainty), or because they do not know if other parties will use the inconclusive estimates of the effect of the emissions reduction as an excuse to avoid cooperation (a combination of social and environmental uncertainty). Moreover, consider the difficulties in identifying which one of the three explanations for the reluctance to cooperate would indeed occur.

One useful way to separate the effects of social from environmental uncertainty is through decision-making experiments. Experiments facilitate the understanding of individual behavior by relying on the study of individual decisions, providing control through the randomization of the "rules of the game," including diverse environmental conditions across different subjects, or across trials within a set of subjects.

In this paper I made a systematic review of experimental studies manipulating the source and magnitude of environmental uncertainty in settings involving the allocation of a common resource. I classify the resource dilemmas depending on whether the strategic setting induces a coordination or a cooperation problem, provide a description of the archetypal game in each case, and finally report the results obtained from the diverse manipulations of environmental uncertainty.

The study of behavioral responses to environmental fluctuations has gained momentum in recent years given the evident connection between environmental uncertainty and climate change.[1] Hence, I include in the paper a selective review of recent experimental social dilemmas inspired by the climate change problem. Our analysis of climate change from this perspective aims to: *i)* connect coordination and cooperation incentives discussed in this paper with the recent strategic settings mimicking the climate change problem, *ii)* describe the findings of this literature and describe a parallel with institutional arrangements for climate

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[1] Climate change is associated to an increase in the fluctuations of fish and water stocks (Vörösmarty et al. 2000; Perry et al. 2005). Environmental fluctuations due to climate change have also created methodological difficulties to compute the intertemporal valuations of the social cost of carbon (Webster 2003; Brock and Hansen 2017).

change; and *iii)* highlight questions that can be addressed with the use of experimental social dilemmas with uncertainty in the climate change context.

2. Two paradigms for the analysis of environmental uncertainty

Behavioral models can introduce environmental uncertainty in two different ways. The first paradigm transforms uncertainty into relative weights indicating the likelihood of occurrence of each potential state of nature. This is the expected utility perspective, in which individuals choose their actions after computing a weighted average of the utility derived from all the potential uncertain outcomes. These weights are given by a probability distribution for the uncertain outcome, a measurable notion of uncertainty defined as risk (Knight 1921).

The "risk exposure" hypothesis is the result of applying the expected utility perspective to CPR management when a greater exploitation of a common resource increases the payoffs' variability. Since subjects typically prefer low variability in their payoffs, uncertainty is socially desirable because it provides individual incentives to decrease the profit share derived from exploiting the common resource (Sandler and Sternbenz 1990; Bramoullé and Treich 2009).

The second paradigm conceives uncertainty as an element directly affecting decision-making, instead of a weighting artifact (Kopelman et al. 2002). Environmental fluctuations might distort social norms (e.g. a 50–50 fairness heuristic) and the notion of how one's decisions affect others' outcomes. As a consequence, individual differences in social orientation become the driver of choices under uncertainty (Roch and Samuelson 1997; de Kwaadsteniet et al. 2006). Uncertainty is socially undesirable under this paradigm because it leads to self-serving interpretations of resource fluctuations.

3. Review of relevant studies

I conducted our study search in five different, freely available, academic search engines: Google Scholar,[2] Mendeley, EconBiz, IDEAS Repec, and PubPsych. I used five different sets of keywords, all of them included *uncertainty* as a keyword. I present, within each bracket, the additional keywords in each set: {*common pool resource, experiment*}, {*common pool resource*}, {*resource dilemma, experiment*}, {*tragedy of the commons, experiment*}, {*tragedy of the commons*}. For Google Scholar, I performed the search using the default order (by relevance) and ordered by year of publication (from most to least recent to detect grey literature). There was no date restriction in the selection of studies.

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[2] The increasing coverage of Google Scholar makes it a powerful database of scholarly literature, compared to paid, controlled databases such as Web of Science and Scopus (Halevi et al. 2017). The main criticism for using Google Scholar, the quality of resources indexed, is not an issue in our case because it allows us to track grey literature, and hence decrease the concerns related to publication bias.

I read the title and abstract of the top one hundred results from each search engine. Studies selected for the study must meet two inclusion criteria based on the title and abstract: 1) implementation of experimental methods with human subjects; and 2) manipulation of at least one source of environmental uncertainty in the experiment. The set of studies satisfying both inclusion criteria were then subject to an exclusion criterion: 3) the single experimental social dilemma covered in the study was a public goods game. The final sample includes 33 studies published between 1990 and 2014 (see the list of studies in Table A1 in the appendix).

According to the latter criterion, I exclude experimental public goods games from this review unless they are compared to a resource dilemma within the same study. The reason is that the two settings are sufficiently different, and the public goods games literature is abundant enough[3] that it requires a separate review. In a public goods game the social dilemma dwells on the individually costly, though socially desirable, provision of a public good (Ledyard 1995). In the common pool resource problem the dilemma dwells on the individually profitable, though socially undesirable, overappropriation of the common good. However, the differences between these two games go beyond the "contribution" versus "appropriation" framing. The public goods game has an egalitarian distributional structure: regardless of who contributes, all group members benefit equally from allocations to the public good. By contrast, the resource dilemma has a proportional distributional structure that captures the resource's rivalry (Apesteguia and Maier-Rigaud 2006).

4. The resource dilemma as a coordination game

4.1. The canonical model

This resource dilemma involves n players jointly and simultaneously appropriating a resource of size S. Each subject i makes a request $x_i \in \{0, S\}$. Individual requests are granted if and only if the total request of all n players, $X \equiv \sum_{i=1}^{n} x_i$, does not exceed the available stock size S. Otherwise, the subject's payoff is reduced by an amount $h(X, S) \in [0, 1]$. The function $h(X, S)$ represents the severity of the resource's deterioration (Aflaki 2013). For instance, if the payoffs are exponentially discounted according to the distance $X - S$, the payoff function is:

$$\pi_i(x_i,\, X,\, S) = \begin{cases} x_i & \text{if } X \leq S \\ x_i e^{-k(X-S)} & \text{if } X > S \end{cases}$$

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[3] See, for instance, Berger and Hershey (1994), Dickinson (1998), Wit and Wilke (1998), Gangadharan and Nemes (2009), Blanco et al. (2016), and Cárdenas et al. (2017) for public goods games with at least three players; and see Bereby-Meyer and Roth (2006) and Fudenberg et al. (2012) for the two-player version of the public goods game.

where the parameter k represents the severity of the consequences from exceeding S. The deterioration function becomes a step-level function when $k \to \infty$, meaning that the payoff becomes zero if the total request exceeds the available stock.

This model introduces environmental uncertainty through an unknown and uniformly distributed stock size $S \sim U[\alpha, \beta]$, with α and β being the minimum and maximum possible stock levels, respectively. Exceeding the unknown stock size mimics a situation in which aggregate pressure over the resource triggers a dynamic path in which deterioration is irreversible [e.g. depleting groundwater beyond a limit leads to the leaking of saline or contaminated water (Konikow and Kendy 2005)].

In game theoretic terminology, the Nash equilibrium is a strategy from which individuals do not have incentives to deviate. For the coordination resource dilemma, the Nash equilibrium is:

$$x^* = \begin{cases} \alpha/n & \text{if } n\beta < (n+1)\alpha \\ \beta/(n+1) & \text{if } n\beta \geq (n+1)\alpha \end{cases} \tag{1}$$

Intuitively, subjects agree to evenly share the lower bound α when there is little uncertainty (i.e. $\beta - \alpha$ is small). Above a given threshold of $(\beta - \alpha)$, the subjects switch to a probabilistic, and more cautious, share of the upper bound β. Precautionary behavior is reflected in the larger denominator, $n + 1$ (Aflaki 2013). Given the severe deterioration occurring when $X > S$, subjects have a strong incentive to coordinate on a division rule, egalitarian or not, to split the stock S based on their requests. Once a division rule is set, downward deviations decrease profits, and upward deviations increase the probability of a null payoff.

Budescu et al. (1990) set up an experimental game with five players per group, an average stock size $\mu_S = 500$, and three uncertainty levels $(\beta - \alpha) \in \{0, 500, 1000\}$. They found that the aggregate request X increased with the uncertainty level. Uncertainty also increased the others' expected total request ($E[X_{-i}]$), and the expected stock size ($E[S]$). The simultaneous increase in $E[X_{-i}]$ and $E[S]$ suggests that subjects raised their own request X_i for profit reasons, not for fairness reasons (i.e. they were not aiming to "bust the pool" to punish an expected large request from others).

The theory predicts a positive relationship between uncertainty and total request only if $(\beta - \alpha)$ is large enough [see eq. (1)]. The authors conducted a similar experiment including smaller uncertainty levels $(\beta - \alpha) \in \{10, 70, 200, 380, 560\}$, holding constant the average stock size $\mu_S = 500$, to test the non-monotonic effect of uncertainty (Budescu et al. 1995a). They found that subjects were less sensitive than predicted to changes in uncertainty levels, and only 31 of 60 subjects behaved according to the non-monotonicity hypothesis.

Budescu et al. (1990) also explored asymmetric payoffs by assigning, to each participant, different exchange rates to cash out the requested resource. They found that requests were inversely proportional to the square root of the exchange rate. For instance, if Subject A could receive twice the payment per requested unit

with respect to Subject B, Subject A requested about 70% of the amount requested by Subject B.

Asymmetric payoffs can also be introduced with a bonus for the smallest individual request, or with a penalty for the largest individual request. Rapoport and Au (2001) found that uncertainty increased the requested amounts in the presence of penalties, although not in the presence of bonuses. One potential explanation for the undesired effects of the penalty is that the corresponding deduction only applied in case of a successful request ($X < S$). This rule provides incentives to make a request large enough to offset the cost of the penalty.

A recent study by Botelho et al. (2013) employed the resource dilemma with uncertain stock size to determine the endowments for a cooperation game played after. Making subjects aware that the endowment in the cooperation game depended on a successful resource request in the initial resource dilemma was sufficient to induce smaller requests in this initial game. A determinant assumption of this study is the full replenishment of the stock size after every round. In a different study, Botelho et al. (2014) replaced the full replenishment between rounds by the following condition: the game ended before the terminal round if, in any given round, the aggregate request exceeded the unknown stock size ($X > S$). This threat of abrupt termination of the game makes it very costly to exceed the unknown stock size. However, the threat was not sufficient to induce individual restraint among subjects. Instead, subjects rapidly depleted the resource by making large requests early in the game, as if they anticipated large requests from others that will terminate the game. The size of stock uncertainty had a similar effect. Although one would expect greater restraint with large uncertainty (i.e. more extreme boundaries in the distribution), it accelerated the stock depletion.

Joireman et al. (2009) studied warnings about resource depletion using a dynamic resource dilemma with unknown stock size and a limited (and bogus) informational structure. Subjects were told to withdraw water from a reservoir of unknown size. Four rounds before the terminal round, they were warned that the resource "is almost exhausted." This warning, in the absence of any objective information about stock size, decreased extraction levels during three periods. However, the extraction returned to the pre-warning levels after the third round. Subjects seem to interpret the warning as a false alarm because exhaustion was never observed. This behavior is similar to the crying wolf problem, observed after repeated hurricane evacuation orders when some of them are interpreted as false alarms (Dow and Cutter 1998).

4.2. Adding sequentiality to the dilemma

In sequential resource dilemmas, subjects take turns to request an amount of resource from a common pool resource of unknown size. Sequential resource dilemmas introduce two potential sources of uncertainty. First, the position in the request sequence is a source of environmental uncertainty, typical of linear

common goods such as irrigation channels (Janssen et al. 2011). Second, the aggregate request from preceding group members is a source of social uncertainty that gives to the resource dilemma the structure of a bargaining game. When tail-enders know the preceding players' requests, they may threaten to make unexpectedly large resource requests, aiming to "bust" the pool if the previous requests are considered unfair.

Table 1 summarizes the findings from sequential studies, noting the informational structure and the effect of uncertainty on individual requests. I also report the *position effect*, a behavioral regularity describing a positive correlation between request position and request size.

The sequential protocol, introduced by Rutte et al. (1987) , is characterized by perfect information about both the request position and the preceding aggregate request. The reported studies did not implement the sequential game with players in multiple positions. Instead, all subjects made their requests as if they were in position 5 (out of 6 subjects) to test whether the causal attribution of previous requests affected the subject's decision. Environmental attribution was triggered by revealing that the (bogus) subject in position 4 did not know the stock size before making a choice. In the social attribution condition, by contrast, it was revealed that the (bogus) subject in position 4 did know the stock size. When attribution is environmental, subjects equally divide the remaining stock between themselves and the (bogus) subject in position 6. When attribution is social, subjects behave reciprocally: they choose more generous allocations if

Table 1: Evidence of uncertainty effects and positional effects in sequential resource dilemmas.

Informational structure of the resource dilemma	Game			
	Sequential	Positional	Cumulative	Self-paced sequential
Is the request position known?	Yes	Yes	No	Yes (endogenous)
Is the precedent aggregate request known?	Yes	No	Yes	Yes
[Uncertainty Effect]/[Position Effect]				
Budescu et al. (1992)	[+]/[Yes]			
Budescu et al. (1995a)	[NA]/[Yes]			
Budescu et al. (1995b)	[+]/[Yes]	[+]/[Mixed]		
Suleiman et al. (1996)[a]	[+]/[Yes]			
Budescu et al. (1997)	[NA]/[Yes]	[NA]/[Yes]	[NA]/[Yes]	
Budescu and Au (2002)	[NA]/[Yes]	[NA]/[Yes]		
Au and Ngai (2003)[b]	[−]/[Yes]			[−]/[Yes]

[a]Fixed positions in the sequential protocol; [b]Uncertainty in group size rather than in stock size. The top panel of Table 1 shows the taxonomy of sequential resource dilemmas as a function of the informational structure. The bottom panel of Table 1 lists studies employing at least one of these sequential games. I report, for every game covered in each study, whether uncertainty had a positive [+] or negative [−] effect on the individual requests. Studies without any variation in environmental uncertainty are reported as [NA].

the remaining stock is abundant, and more selfish allocations if the remaining stock is scarce.

Budescu et al. (1992 and 1995b) assigned participants to every position in the request sequence to study the positional effect. Both studies focused on the first-mover advantage with respect to the requests of subsequent group members, and with respect to the requests in the simultaneous resource dilemma. Budescu et al. (1992) compared the predictive power of the Nash equilibrium with respect to a focal point acting as a norm (i.e. equal-sharing). Budescu et al. (1995b) criticized the lack of predictive power from the Nash equilibrium, explained by the bargaining power of tail-end players.

A potential explanation for the position effect is that within-round fairness is a minor concern because the rotation over different positions creates fairness between-rounds (Budescu et al. 1992, 1995a). Suleiman et al. (1996) manipulated the deservingness of a request position held for multiple trials of the resource dilemma. The allocation of request positions using an auction or a test score in a general knowledge quiz induced high deservingness, whereas the random allocation of request positions induced low deservingness. The high deservingness condition replicated the position effect observed with rotating positions. By contrast, the low deservingness condition drastically diminished the position effect.

If the position effect captures a preference for efficiency (i.e. subjects making a late request prefer a small payoff rather than exceeding the stock size with a larger request), the results should be identical to the simultaneous dilemma if information on previous requests is not available. In the positional protocol, subjects know their turn to make a request but do not know anything about previous requests. Despite the sequential structure of the choices, the information structure should not differ from the simultaneous resource dilemma,[4] and therefore the positional effect should not be observed in the positional protocol. Nevertheless, Budescu et al. (1995b) showed, in two separate experiments, that the position effect persisted even without information about the preceding aggregate request. Moreover, elicited beliefs revealed that subjects expect that others will exploit the early-mover advantage.

Budescu and Au (2002) proposed a "positional entitlement norm" that rationalizes the position effect without information on the previous aggregate request. The authors fit the parameters of their theoretical model using experimental data from the positional protocol, in which the aggregate previous request is unknown. Then, they test the model's predictive power with data from the sequential protocol, in which the aggregate previous request is available. The authors report high accuracy of predictions, providing support to the positional entitlement hypothesis.

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[4] Imagine a simultaneous resource dilemma conducted by hand in which the experimenter collects the decisions in a specified order that is common knowledge. The sequence is known but the previous actions do not, as in the positional protocol.

In the cumulative protocol, subjects are informed about the preceding aggregate request, but they do not receive any information about their request position. Budescu et al. (1997) compared the cumulative with the sequential and positional protocols and found evidence of the position effect in all three of them. Hence, the evidence suggests that sequential dilemmas only require partial information, whether about position request or previous aggregate requests, to trigger the position effect.

Thus far, I have discussed sequential resource dilemmas that have focused on understanding and quantifying the position effect under different informational structures. Elicited beliefs also showed that subjects expect others to profit from the early mover advantage. One question to address is whether subjects profit from the first-mover advantage when request positions are simultaneously decided with the request size. Au and Ngai (2003) explored this question using the self-paced sequential (SPS) protocol, in which each one of the n subjects decides in which of the n available rounds she wants to submit her request. If every subject profits from the first-mover advantage, all requests would occur in the first round, and the SPS protocol would simplify to the simultaneous protocol.

The SPS protocol manipulates group size uncertainty rather than stock size uncertainty. Group size is uniformly distributed between 3 and 7, and the results are compared to a known group size of 5 (the expected value under uncertainty). The results show that group size uncertainty decreases the requests and decreases the number of subjects behaving as first movers. The negative effect of an uncertain group size on the request, contrary to the effect of an uncertain stock size, was also found by de Kwaadsteniet et al. (2008).

4.3. Three confounding explanations for the effect of uncertainty

Stock uncertainty increases the size of requests in the simultaneous and the three sequential protocols. Three confounding explanations have been proposed (Budescu et al. 1992; Biel and Gärling 1995). First, subjects could have misinterpreted the probability distribution of the stock size, making overoptimistic requests that would be individually profitable in case of success. This is what Biel and Gärling define as an *outcome desirability* bias. The second explanation also involves misinterpretation of the probability distribution of the stock size, but not necessarily in a self-serving manner. This erratic behavior is defined as a *perceptual* bias. Third, the environmental fluctuations triggered by uncertainty allow subjects to rely more on their own social orientation (or social preferences) instead of following a social norm such as equal-sharing. Because subjects with a selfish orientation profit more from the environmental uncertainty, this behavior is defined as an *egoism* bias.

Gustafsson et al. (1999b) proposed an experimental design to disentangle the three confounding explanations for the effect of stock size uncertainty. In this design, subjects are assigned to either an *individual guess* task, in which the subject must make an estimate of the stock size; to an *individual request* task,

a variation of the simultaneous resource dilemma in which the subject's fellow group members mimic her own request; or to a *group request* task, identical to the simultaneous resource dilemma. The perceptual bias can be ruled out if the individual and group requests, but not the guesses, are positively correlated with the uncertainty level. Similarly, one can rule out the outcome desirability bias if only the group requests are positively correlated with the uncertainty level.

The authors conducted two related studies supporting the presence of an outcome desirability bias. In the first study, they compared request levels when subjects observed fifteen draws from the distribution of the stock size, either sequentially or simultaneously, before making their choice (Gustafsson et al. 1999a). The request levels were larger after observing sequential draws, leading the authors to argue that this was due to imperfect recall, a mechanism behind outcome desirability. In the second study, the subjects were informed about their fellow group members' total request, after which they could modify their requests (Gustafsson et al. 2000). The authors interpreted the absence of selfish behavior in the experiment as support for the outcome desirability hypothesis. Nevertheless, an alternative explanation is that perceived greediness, or generosity, is triggered by deviations from an equal-sharing norm.

Wilke (1991) elaborated on this reasoning and argued that greed is constrained by the desire for efficient resource allocation, but environmental and social uncertainty reduce the constraint. The experimental results showed that the election of group leaders, and the endorsement of these leaders when they acted in an efficient way, decreased uncertainty and strengthened the constraints over greed. An alternative and efficient way to constrain greed in the presence of environmental uncertainty is to ask subjects to justify their request decision to fellow group members (de Kwaadsteniet et al. 2007).

Gustafsson et al. (1999b) focused on the comparison of the outcome desirability bias with the egoism bias but left unexplored other traits of social value orientation (SVO) like cooperativeness, altruism and spitefulness. SVO can be measured using the Ring test: a set of questions involving a choice between two hypothetical allocations between herself and someone else (Liebrand and McClintock 1988; Van Lange et al. 1997). Subjects can be categorized into four types of orientations. In order of increasing concern for social well-being, categories include: competitors, endowed with spiteful preferences; individualists, characterized by a profit-maximizing behavior; cooperators, maximizers of mutual gains; and altruists, willing to sacrifice their own gains to increase others' profits.

Budescu et al. (1997) measured the SVO and compared the request size for each orientation type in the simultaneous and the sequential resource dilemmas. In the simultaneous protocol, the size of requests matched the ranking for social well-being (i.e. competitors requested more than individualists, individualists requested more than cooperators, and so on). However, there was no statistically significant role for SVO in the sequential game. One explanation for this lack of significance in sequential games is that social orientations are better predictors of

behavior in less structured decision environments (Snyder and Ickes 1985); and sequential decisions provide sufficient structure to weaken the effects of SVO.

De Kwaadsteniet et al. (2006) also measured SVO and found a positive correlation between request size and stock uncertainty for competitors and individualists; whereas this correlation was not different from zero for cooperators and altruists. In addition, de Kwaadsteniet et al. (2008) found a negative correlation between request size and uncertainty for cooperators and altruists when the source of uncertainty is group size; whereas the correlation was not different from zero for competitors and individualists.

The studies measuring SVO suggest that an equal-sharing rule is applied in cases of resource certainty, whereas resource uncertainty makes subjects more likely to rely on their social orientation. Moreover, since large requests are costlier under group size uncertainty than under stock uncertainty, the latter scenario induce self-restraint among the subjects more socially oriented, and the former scenario induces greediness among the more competitive and individualistic subjects.

5. The resource dilemma as a cooperation game

5.1. Switching from coordination to cooperation incentives

Consider n symmetric players jointly appropriating a resource of size S. Each subject i chooses an appropriation level $x_i \in \{0, x_{max}\}$, with $x_{max} \leq S/n$. Each appropriated unit gives a benefit B only to the appropriator, whereas each non-appropriated unit provides a smaller benefit $b < B$ to all group members. This setting evokes a social dilemma when the social benefits of non-appropriation exceed the private benefits from appropriation, or $nb > B$. A tension between collective and private incentives arises because the condition $b < B$ makes appropriation individually more profitable, even if non-appropriation yielded a higher social benefit nb. Consider for instance the social dilemma occurring with timber harvesters exploiting a forest with collective property rights. Timber extraction has a larger private value for the harvester with respect to not cutting down the tree. However, in the model above, the deforestation costs for society exceed this private value, even for the first piece of timber. The linearity behind this assumption simplifies the strategic environment and maximizes the difference between the individually rational and the socially optimal strategies. This assumption is abandoned in Section 5.2.

The difference in incentives, in comparison to the coordination resource dilemma, arises from the value assigned to a non-appropriated unit. The value in a cooperation dilemma is nb, to be equally divided among group members. Because $nb > B$, this is a positive-sum game in which social benefits increase with restrained appropriation. By contrast, in the coordination dilemma the value of a non-appropriated unit is zero. This is a constant-sum game because subjects are dividing a stock with fixed (but unknown) size, in which the gains from restraining the request size is a reduction in the probability of obtaining a null payoff.

A good comparison of coordination and cooperation incentives is shown in de Vries and Wilke (1995). They compared a coordination game, in which the condition $X > S$ yielded a null payoff, with a cooperation game, in which the excess request $X - S$ yielded a penalty to be equally shared among group members. In the cooperation game, subjects had incentives to request greater values than their fellow group members because the benefits from a large request were individual, while the penalty costs of exceeding S were divided among the group.

The cooperation resource dilemma also evokes comparison with the public goods game. Recall that, unlike the resource dilemma, in a public goods game the socially desired outcome is the voluntary, though individually costly, provision of a public good. The games are strategically equivalent when the effects that one's actions have into the payoffs of others are linear. Nevertheless, the framing differences associated with appropriation versus provision of the public good do have an effect.[5]

Van Dijk et al. (1999) have argued that, under uncertainty, the resource dilemma and the public goods game evoke different social cues: the former evokes fairness consideration and the latter evokes the provision of the public good. Therefore, in a social dilemma with uncertainty, groups adopt coordination rules that do not rely on the unknown information. For instance, uncertainty in others' endowment did not alter behavior in resource dilemmas but affected the fairness rule employed in a public goods game (i.e. subjects switch from a proportional contribution with certainty to an egalitarian contribution under uncertainty). By contrast, uncertainty in the distribution of a bonus altered the fairness rule adopted in the resource dilemma (i.e. subjects switched from the minimization of payoff differences to an inverse proportionality in appropriation), but not in the public goods game.

Some recent cooperation dilemmas included the joint decisions of provision and appropriation of a common good, mimicking the incentives for maintenance and use of commons like irrigation channels and pastures. Anderies et al. (2013) compared the effects of environmental uncertainty in a first provision stage (a shock to infrastructure affecting maintenance of the irrigation system), with respect to uncertainty in a second appropriation stage (a shock in the water supply). In this study, uncertainty increases the fragility of cooperative outcomes, especially when the shocks affect the provision stage.

5.2. Non-linear static resource dilemmas

The linear resource dilemma is easy to grasp and is comparable to the public goods game, but its simplicity comes at the cost of not capturing the complexity of socio-ecological interactions. Non-linear resource dilemmas capture the idea that a positive degree of resource appropriation, determined by the maximum sustainable yield, might be socially desirable. In the seminal experimental

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[5] See, for instance, the studies by (Andreoni 1995; Sell and Son 1997; Cox et al. 2013).

setting described in Ostrom et al. (1992), each of n ubjects choose how many tokens x_i they want to allocate into the common resource. A subject's payoff is given by:

$$\pi_i(x_i,\, X_{-i}) = \begin{cases} we & \text{if } x_i = 0 \\ w(e - x_i) + (x_i / X) \cdot F(X) \end{cases}$$

where w represents the opportunity cost of extraction, $X = \sum_{i=1}^{n} x_i$ is the aggregate extraction, and $F(X)$ is the resource's production function. The notion of rivalry, a characteristic of common property goods not shared with public goods games (Apesteguia and Maier-Rigaud 2006), is captured by the fact that the gains from $F(X)$ are distributed in a proportional rather than an egalitarian manner, as indicated by the term x_i/X.

Experimental settings involving multiple trials of the non-linear CPR game implicitly assume full resource replenishment after every interaction. This simplification allows to study the effect of uncertain game duration without confounding its effect with notions of depletion or scarcity. Walker and Gardner (1992) designed a repeated CPR game with a probability of termination increasing in the aggregate extraction of the group. They found that the introduction of a "safe zone," an extraction interval with a null probability of termination, decreased the average extraction level. Muller and Vickers (1996) replicated this design, and found that introducing communication is efficiency-enhancing, conditional on the endogenous emergence of a leader.

Apesteguia (2006) manipulated uncertainty in outcomes by comparing extraction levels in a CPR game with and without information about the payoff function. Each round, participants were informed about the total, average, and marginal payoffs from the extraction of the common resource, and about the group's total investment. The experimental results showed that the average extraction levels did not vary with knowledge of the payoff function.

5.3. Dynamic and intergenerational resource dilemmas

In dynamic resource dilemmas, characterized by not having a full stock replenishment between trials, the contemporary appropriation level affects the future availability of the common resource. This notion of intertemporal CPR rivalry adds another environmental dimension susceptible to uncertainty: the resource's growth rate.

Hine and Gifford (1996) compared the extraction patterns with and without information about the growth rate interval. Their experiments also controlled the provision of an interval for the stock size. Uncertainty in the growth rate, and in the stock size, increased the extraction rate. The authors argued, as did de Kwaadsteniet et al. (2006), that environmental uncertainty decreases the salience of social norms due to a weaker link between the abstract goal (i.e. cooperation) and the concrete behavior (i.e. low extraction).

Roch and Samuelson (1997) provided subjects with an interval for the growth rate in the resource dilemma, and then compared environments with small versus large intervals. Holding the mean growth rate constant, a larger interval of the resource's growth rate induced higher extraction levels. The authors measured SVO using the Ring test and argued that the effect was driven by competitive and individualistic types, who interpreted high-fluctuations in the growth rate as an environmental cue inviting them to increase their personal profit.

Moxnes (1998, 2000) argued that sub-optimality in the management of dynamic resources is partly explained by the fact that people base their decisions on immediate feedback and overlook the full dynamic effect due to the environmental complexity. Experimental evidence supporting this argument was collected in a game with perfect property rights over a fishery (i.e. there was no social dilemma). Those overinvesting in their fishing-fleet tended to overuse it, whereas those underinvesting in their fleet tended to underuse it.

Another perspective to the dynamic management of common resources involves intergenerational concerns. In this context, the cooperation game can model a renewable open-access resource involving users from multiple generations. Uncertainty is explored by comparing subjects not knowing their generational position, and from whom greater fairness concerns are expected, with respect to subjects informed about how many people extracted before and will extract after them.

Chermak and Krause (2002) performed this comparison with an experiment in which subjects live in partially overlapped generations (i.e. each subject played for three consecutive rounds out of five rounds). Subjects that were informed of their exact generation easily responded to previous choices. By contrast, subjects uninformed of their generational position adopted a predetermined and more extreme strategy for multiple trials, either a sustainable use or a race to deplete the stock.

Fischer et al. (2004) set up another intergenerational CPR game characterized by non-overlapping generations, and by payoffs written as a function of the extracted share because the stock level is not known. Subjects were only told about the resource's growth rate, which could either be slow or fast (plus a treatment with full replenishment at the start of each generation). Not knowing the generational position is presumed to evoke fairness. Therefore, the intergenerational equity solution predicted higher extraction levels with a fast (compared to a slow) resource's growth rate. Nonetheless, the experimental data revealed higher extraction levels with the slow resource's growth rate. This was explained as "optimistic free-riding," a behavior in which subjects exploited the resource for their own profit with the expectation that others would restrain their appropriation.

6. Uncertainty and the climate change problem

Climate change is the most relevant collective action problem faced at the present time, and one in which both environmental and social uncertainty shape potential

outcomes. Environmental uncertainty encompasses climate projections and the severity of the consequences for not meeting abatement goals. Social uncertainty encompasses the strategic incentives for committing to climate change agreements, as well as the temporal lag between abatement costs, paid upfront, and the future benefits of cooperation agreements (Raihani and Aitken 2011). In this section I cover a set of experimental studies in the context of climate change, some of them selected apart from the systematic search procedure.

I start by briefly mentioning the demand for information about the scientific understanding of climate change and its potential outcomes. Milinski et al. (2006) reported altruistic behavior when the contributions in a public goods game would fund press advertisements about climate change, especially when the participants received expert information about related research. A similar willingness to cooperate was reported in hypothetical resource dilemmas based on real-world issues (e.g. overfishing in Lake Michigan and water conservation in urban Arizona), when the uncertainty about a catastrophic outcome was reduced (Kortenkamp and Moore 2006).

In the rest of the section our focus will be on the study of individual incentives for abatement.

A first approach proposes a collective-risk social dilemma (CRSD hereafter). In the CRSD, proposed by Milinski et al. (2008), each group member chooses how much of her endowment she wants to contribute to a public fund in each of several rounds. A catastrophic outcome occurs with a positive probability if the contributions to the public fund do not reach a known threshold in the terminal round of the game. The "no rebate" condition from the public fund resembles typical burden-sharing incentives in the climate change problem: countries are aware that total emissions should be reduced, but they find it economically profitable to minimize their own contributions to the public fund. A similar, one-shot game was introduced in Messick et al. (1988). When the threshold was not met, a catastrophe yielding a null payoff to all group members occurred with a probability of 0.5. Messick et al. found positive effects of communication and leadership on the reduction of social uncertainty.

In Milinski et al. (2008) the probability of a catastrophe $p \in \{10\%, 50\%, 90\%\}$, yielding a null payoff in the CRSD, varies across treatments. Note that uncertainty is maximized when $p = 50\%$. In the other two scenarios the catastrophe is either very unlikely, or very likely. Milinski et al. (2008) found that p had to be very large to induce contributions that reach the threshold (for p equal to 10%, 50%, and 90%, the number of successful groups was 0/10, 1/10, and 5/10, respectively). Hence, it is the expected cost of the catastrophe, not uncertainty, what drives contributions upward.

Milinski et al. (2011) introduced endowment heterogeneity and an intermediate target to the CRSD. If the target is not met by the fifth out of ten rounds, the catastrophic event might occur in each of the remaining five rounds with positive probability. Groups of "rich" participants always meet the final target. By contrast, groups of "poor" participants only have a positive chance of meet-

ing the final target in the presence of an intermediate target. Mixed groups, with "rich" and "poor" participants, are halfway the two types of homogeneous groups. In another CRSD, Tavoni et al. (2011) added non-binding communication to mixed groups with "rich" and "poor" participants. The intermediate target in Milinski et al. (2011) and the non-binding communication in Tavoni et al. (2011) allow "rich" participants from successful groups to signal their intention to redistribute.

The second approach to social dilemmas subject to catastrophic outcomes introduces uncertainty in the contribution threshold. Barrett and Dannenberg (2014) predict, from a game theory perspective, that a known threshold creates the incentives for a coordination dilemma, whereas an unknown threshold provides incentives to not contribute and free ride on others' contribution, as in a cooperation dilemma. The authors experimentally validated these predictions and, further, found that with an unknown threshold, parties pledged less than needed and contributed less than what they pledged.

In a following study, the authors found the same results by comparing low versus high threshold uncertainty: low uncertainty creates the incentives of a coordination dilemma, and the fear of crossing the climate change "tipping point" act as a deterrent against self-interested choices (Barrett and Dannenberg 2017). As a result, the catastrophe is avoided in 80% of the groups with small uncertainty, whereas it is only avoided in less than 30% of the groups with larger uncertainty levels. In the same study, subjects vote to choose between playing a cooperation game in which a socially efficient solution (i.e. the first best) is achievable but subjects have incentives to deviate from it; or playing a tipping game, in which a small cost guarantees that an outcome slightly worse than the socially efficient solution (i.e. a second best) becomes an equilibrium. This equilibrium is reached if subjects think that enough group members will choose the same action, and therefore voting to play the tipping game could be used as a signal to coordinate and attain the second best. However, the experimental results show that participants are reluctant to abandon the public goods game.

Uncertainty from contribution thresholds is not always exogenously imposed. Adler (2014) explored an endogenous threshold defined by a player in the role of policy-maker, who could also impose a costly enforcement of this target. When the threshold was endogenously set, and sporadically enforced, the problem of environmental uncertainty became entangled with social uncertainty because of the lack of credibility in enforcing the estimated threshold. Therefore, the extraction level increased, and the common resource's duration gets shorter.

7. Wrapping up

7.1. Pooling the experimental evidence

In this section, I review the collective experimental evidence relating efficiency and multiple sources of uncertainty described in Sections 4 and 5. Figure 1 summarizes the effects on efficiency from the different manipulations of uncertainty,
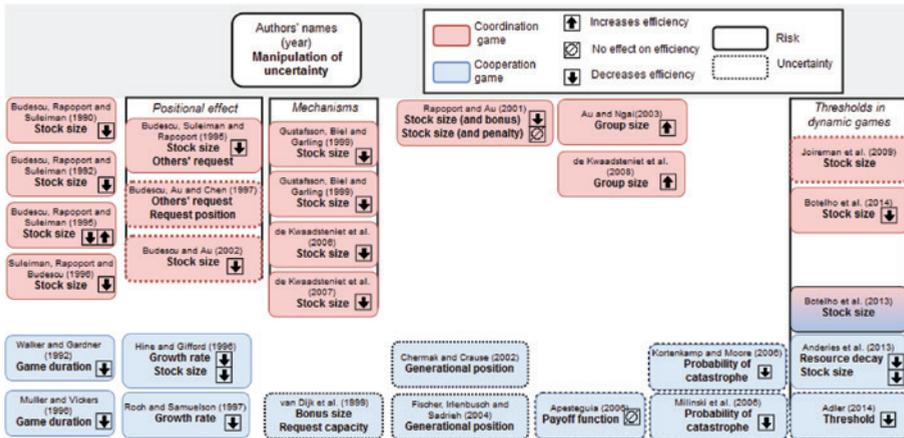
Figure 1: Summary of the effects of environmental uncertainty on efficiency. Each study is represented in a colored box (pink for coordination games and blue for cooperation games), with the authors' names and year of publication, the source of environmental uncertainty (in bold); and whether the uncertainty was measurable as risk (box with continuous border), or unmeasurable (box with dashed border). A small icon on the lower right side indicates whether each study's manipulation of uncertainty leads to an increase, a decrease or has no effect on the efficiency levels. Boxes without such icons indicate that the experimental design manipulates uncertainty, but its effect on efficiency was not directly tested. I list studies chronologically from left to right according to the first time each source of uncertainty was experimentally tested. Coordination games are displayed on top, whereas cooperation games are displayed at the bottom.

grouping studies by dilemma type (coordination or cooperation), source of environmental uncertainty, and measurability of uncertainty.

I draw the following observations from Figure 1:

1. **Most sources of environmental uncertainty have an efficiency-decreasing effect**. They include stock size, game duration, growth rate, the probability of catastrophe (in cooperation games), and thresholds in dynamic games. This efficiency-decreasing effect is driven by two mechanisms: an outcome desirability bias, suggesting that subjects interpret in a self-interested manner the fluctuations caused by uncertainty; and an egoism bias, suggesting that such fluctuations invite subjects to deviate from social heuristics (e.g. equal payoffs) and rely more on their social orientation.

Note that observation 1 favors the rejection of the "risk exposure" hypothesis described in Section 2. That is, the payoff variability created by the environmen-

tal uncertainty does not induce sufficient restraint in the resource exploitation to make uncertainty efficiency-enhancing. Our conjecture is that self-serving interpretations of uncertainty, which act in detriment of efficiency, are more salient than payoff variability when the rewards for participation are not highly correlated with the experimental outcomes. This might occur because the rewards for participation are not correlated with the subjects' decisions (i.e. paying a participation fee), or because a payment based on repeated trials decreases the effects of extreme fluctuations.

I found one exception in which the "risk exposure" hypothesis holds:

2. **Group size uncertainty has an efficiency-enhancing effect**. An uncertain group size makes the equal division rule, or S/n heuristic, harder to apply (de Kwaadsteniet et al. 2008). Under the S/n heuristic, environmental fluctuations in the denominator tend to be more extreme than in the numerator, preventing the development of overoptimistic expectations.
3. **Coordination games focused on stock size uncertainty, whereas cooperation games explored additional sources of uncertainty such as growth rate, game duration and generational position**. The focus on a single source of uncertainty in coordination games provided opportunities for a deep study of the underlying mechanisms (e.g. outcome desirability, egoism bias, social orientation) and the role of sequential requests. By contrast, cooperation dilemmas have been useful to validate the efficiency-decreasing effect of uncertainty in experimental settings that more closely resemble the use of common pool resources.
4. **Uncertainty is not always introduced as measurable risk**. In roughly a quarter of the studies, uncertainty was introduced as absence of information. For instance, as uncertainty regarding the payoff function (Apesteguia 2006), the generational position in a dynamic game (Chermak and Krause 2002; Fischer et al. 2004), or the environmental consequences of shocks (Kortenkamp and Moore 2006; Milinski et al. 2006).

7.2. Uncertainty in current and future climate change experiments

In Section 6 I cover a selective set of studies introducing uncertainty in climate change experiments. These are dynamic contribution games with a threshold that must be met to avoid the risk of a catastrophic outcome. Perhaps the more important result is how the degree of threshold uncertainty transforms the game from one with a unique, inefficient, equilibrium into a coordination game with two equilibria, one of which is individually and socially desirable.

Threshold uncertainty in this dynamic game closely resembles the stock uncertainty from static coordination dilemmas. Hence, according to the observations listed above, one would expect that outcome desirability and egoism remain as the driving mechanisms of low contributions in the presence of threshold uncertainty.

Other environmental sources of uncertainty discussed in the subsection above are not directly relevant in the climate change setting, except for a scenario with multiple generations. Our conjecture is that intergenerational uncertainty might induce greater contributions in the climate change experiment if, for instance, subjects from the latter (but unknown) generation must face a larger risk of catastrophe if the contribution threshold is not met.

A robust result observed in sequential dilemmas is the positional effect, which entails a time-related mover advantage that is detrimental to cooperation. In coordination dilemmas it corresponds to an early mover advantage, allowing subjects to request a larger share of the resource. In the climate change setting it can be thought as a late mover advantage, since countries are not submitting beneficial requests but rather costly abatement goals.

Take for instance the Paris Agreement as an example. Each country must ratify the Agreement by issuing an Intended Nationally Determined Contribution (INDC) to mitigate climate change. However, the INDC is not binding, and the entire Agreement is not ratified, until fifty-five countries who jointly produce at least 55% of total greenhouse emissions issue their own INDC. This timing provides incentives to large polluters to delay the release of their INDC under the excuse that other large polluters have not released it either.

Additional parallels with other international agreements can also be drawn by comparing the tipping point game with the cooperation game. Agreements such as MARPOL[6] and the Montreal Protocol involved some degree of enforcement throughout trade restrictions guaranteeing that, once a critical mass adopted the new technology standards, everyone else had the incentives to follow, as in a coordination game. By contrast, in the Kyoto Protocol the attention was focused on cost-effectiveness rather than on enforcement. In the absence of an agreed enforcement mechanism, it is not possible to create incentives to coordinate that drives actors to the sanction-free outcome (Barrett and Dannenberg 2017).

Climate change experiments have also explored how endowment heterogeneity and non-binding communication affects contributions to the mitigation fund. In particular, I have learnt that large threshold uncertainty provides incentives to turn communication into cheap talk (Barrett and Dannenberg 2012). This strategic behavior can be further exploited to analyze the combined role of subjects' heterogeneity and communication. Consider a game in which one party has more precise information about the threshold (i.e. less uncertainty) and can communicate to the other group members. One could explore whether truthful (i.e. revealing the actual threshold or its interval) or strategic (i.e. misreport the threshold or its interval to induce greater contributions from others) communication emerges, and their effects on the likelihood to meet the threshold. One could expect some subjects not willing to cooperate because they do not expect truthful communication regarding the threshold. This is similar to the lack of credibility of endogenous thresholds determined by a participant acting as policy-maker (Adler 2014).

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[6] The International Convention for the Prevention of Pollution by Ships.

One can also address the interplay between perception of uncertainty and responses to climate change using the CRSD. For instance, one could deliver information about potential catastrophic outcomes using an ambiguity approach with unknown risks, instead of the risk approach with known probabilities. Ambiguity might lead to a pessimistic weighting of potential outcomes, increasing the contributions because the catastrophic event appears to be more likely to occur.

7.3. Final remarks

I surveyed experimental resource dilemma studies manipulating environmental uncertainty. I categorized the studies based on the type of incentives, either as coordination games, in which participants submit a joint request that should not exceed an unknown stock size; or as cooperation games, in which the collective gains from conservation exceed the gains from individual appropriation of the resource. Environmental uncertainty tends to be associated with a decrease in efficiency. The only robust exception to this generalization is the effect of an uncertain group size.

Game theory models have explored the conditions under which uncertainty is efficiency-enhancing or efficiency-diminishing in commons management. Conditions include sources of environmental uncertainty (Aflaki 2013; Fesselmeyer and Santugini 2013; Benchekroun and Long 2014), and functional forms representing the risk aversion of resource users (Bramoullé and Treich 2009; Antoniadou et al. 2013). The incentives modeled in such strategic settings focus on the trade-off between the benefits from exploiting a common resource and the mitigation of risk exposure. However, they often neglect other psychological aspects such as biases in the perceptions of environmental uncertainty (Gustafsson et al. 1999a; Weber 2006), its interplay with social orientation (de Kwaadsteniet et al. 2006) and with affective reactions (Loewenstein et al. 2001; Sundblad et al. 2007).

In the previous two sections of this paper I connected the experimental evidence from social dilemmas with environmental uncertainty to the collective action problem imposed by climate change. A skeptical reader may argue that the results from experimental social dilemmas using standard subject pools cannot be extrapolated to stakeholders' decisions when the countries' economic growth are at play. Even if this is true, the understanding of experimental behavior with this convenience pools remains useful for two reasons. First, it provides "toy models" of the institutional arrangements needed to conceive the climate change problem as a coordination game, not as a cooperation dilemma. Second, the behavior observed in experiments can provide clues on how to communicate scientific results in climate change issues exploiting the uncertainty component. The dissemination of findings and challenges can be useful to increase public awareness regarding the global challenge of climatic change.

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Appendix

Table A1: Studies included in the survey analysis.

Year	Title	Authors	Journal	Search engine	Search terms
2014	Effects of Threshold Uncertainty on Common-Pool Resources.	Adler	Working paper	E	(CU)
2013	Environmental variability and collective action: Experimental insights from an irrigation game.	Anderies et al.	ECOL ECON	G	(CUE)
2006	Does information matter in the commons? Experimental evidence.	Apesteguía	J ECON BEHAV ORGAN	G	(CUE)
2003	Effects of group size uncertainty and protocol of play in a common pool resource dilemma.	Au and Ngai	GROUP PROCESS INTERG	G	(CUE)
2012	Climate negotiations under scientific uncertainty.	Barrett and Dannenberg	PROC. NATL. ACAD. SCI. U.S.A.	G	(TUE)
2013	Linking appropriation of common resources and provision of public goods decreases rate of destruction of the commons.	Botelho et al.	Working paper	E	(CU)
2014	Time and uncertainty in resource dilemmas: equilibrium solutions and experimental results.	Botelho et al.	EXP ECON	G	(RUE)
1997	Effects of protocol of play and social orientation on behavior in sequential resource dilemmas.	Budescu et al.	ORGAN BEHAV HUM DEC	G	(CUE)
1995	Common pool resource dilemmas under uncertainty: qualitative tests of equilibrium solutions.	Budescu et al.	GAME ECON BEHAV	G	(CU)
1990	Resource dilemmas with environmental uncertainty and asymmetric players.	Budescu et al.	EUR J SOC PSYCHOL	G	(CUE)
1992	Simultaneous vs. sequential requests in resource dilemmas with incomplete information.	Budescu et al.	ACTA PSYCHOL	G	(RUE)
2002	A model of sequential effects in common pool resource dilemmas.	Budescu et al.	J BEHAV DECIS MAKING	G	(CUE)
1995	Positional order and group size effects in resource dilemmas with uncertain resources.	Budescu et al.	ORGAN BEHAV HUM DEC	G	(CUE)
2002	Individual response, information, and intergenerational common pool problems.	Chermak and Krause	J ENVIRON ECON MANAG	G	(CUE)

Table A1 (continued)

Year	Title	Authors	Journal	Search engine	Search terms
2008	How many of us are there?': Group size uncertainty and social value orientations in common resource dilemmas.	de Kwaadsteniet et al.	GROUP PROCESS INTERG	G	(RUE)
2007	Justifying decisions in social dilemmas: Justification pressures and tacit coordination under environmental uncertainty.	de Kwaadsteniet et al.	PERS SOC PSYCHOL B	G	(RUE)
2006	Social dilemmas as strong versus weak situations: Social value orientations and tacit coordination under resource size uncertainty.	de Kwaadsteniet et al.	J EXP SOC PSYCHOL	G	(RUE)
2004	An intergenerational common pool resource experiment.	Fischer et al.	J ENVIRON ECON MANAG	G	(CUE)
1999	Outcome-desirability bias in resource management problems	Gustafsson et al.	THINK REASONING	G	(CUE)
1999	Overharvesting of resources of unknown size.	Gustafsson et al.	ACTA PSYCHOL	G	(CUE)
1996	Individual restraint and group efficiency in commons dilemmas: The effects of two types of environmental uncertainty.	Hine and Gifford	J APPL SOC PSYCHOL	G	(RUE)
2009	The environmentalist who cried drought: Reactions to repeated warnings about depleting resources under conditions of uncertainty.	Joireman et al.	J ENVIRON PSYCHOL	G	(CUE)
2006	Time, uncertainty, and individual differences in decisions to cooperate in resource dilemmas.	Kortenkamp and Moore	PERS SOC PSYCHOL B	G	(CUE)
1998	Not only the tragedy of the commons: misperceptions of bioeconomics.	Moxnes	MANAGE SCI	G	(TUE)
2000	Not only the tragedy of the commons: misperceptions of feedback and policies for sustainable development.	Moxnes	SYST DYNAM REV	G	(TUE)
1996	Communication in a Common Pool Resource Environment with Probalistic Destruction.	Muller and Vickers	Working paper	I	(CUE)
2001	Bonus and penalty in common pool resource dilemmas under uncertainty.	Rapoport and Au	ORGAN BEHAV HUM DEC	G	(CU)
1997	Effects of environmental uncertainty and social value orientation in resource dilemmas.	Roch and Samuelson	ORGAN BEHAV HUM DEC	G	(RUE)
1996	Fixed position and property rights in sequential resource dilemmas under uncertainty.	Suleiman et al.	ACTA PSYCHOL	G	(CUE)
1999	Inequality, communication, and the avoidance of disastrous climate change in a public goods game.	Tavoni et al.	P NATL ACAD SCI USA	G	(TUE)

Table A1 (continued)

Year	Title	Authors	Journal	Search engine	Search terms
1999	What information do we use in social dilemmas? Environmental uncertainty and the employment of coordination rules.	van Dijk et al.	J EXP SOC PSYCHOL	G	(RUE)
1992	Probabilistic destruction of common-pool resources: Experimental evidence.	Walker and Gardner.	ECON J	G	(CUE)
1991	Greed, efficiency and fairness in resource management situations.	Wilke	EUR REV SOC PSYCHOL	G	(CUE)

Keys for search engines: Google scholar (G), Mendeley (M), EconBiz (E), IDEAS Repec (I), and PubPsych (P). Keys for search terms: {common pool resource, uncertainty, experiment} : (CUE); {common pool resource, uncertainty} : (CU); {resource dilemma, uncertainty, experiment} : (RUE); {tragedy of the commons, uncertainty, experiment} : (TUE).