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The effect of environmental uncertainty on the tragedy of the commons

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ABSTRACT

We model a common pool resource game under environmental uncertainty, where individuals in a symmetric group face the dilemma of sharing a common resource. Each player chooses a consumption level and obtains a corresponding share of that resource, but if total consumption exceeds a sustainable level then the resource deteriorates and all players are worse-off. We consider the effect of uncertainty about the sustainable resource size on the outcome of this game. Assuming a general dynamic for resource deterioration, we study the effect of increased ambiguity (i.e., uncertain probabilities pertaining to the common resource's sustainable size). We show that whereas increased risk may lead to more selfish behavior (i.e., to more consumption), increased ambiguity may have the opposite effect.

1. Introduction

The problem of sharing common resources underlies many large-scale conflicts among human societies today. Mega-challenges such as global warming, international consumption of Earth's nonrenewable resources, and nuclear proliferation all necessarily involve tensions between individual rationality and social efficiency as regards a focal resource. A single country may benefit from not investing in clean-energy technologies and from using cheaper energy sources (e.g., coal), but those choices lead to pollution of the global commons through increased greenhouse gas emissions to the atmosphere. Similarly, greater consumption of a natural resource, such as fish, is individually desirable but at the aggregate level leads to overfishing and potentially catastrophic thinning of the world's fish population. Such social dilemmas were popularized in a *Science* article by Hardin (1968), although an earlier version of the problem was described by Lloyd (1977) and can be traced back to Aristotle (see Barker, 1948). These problems have been extensively studied in social psychology (Kopelman et al., 2002) and political science (Ostrom et al., 1992) as well as in decision sciences and economics; see, for example, Kollock (1998) and the references therein.

This paper focuses on an important category of social dilemmas: the *common pool resource* (CPR) game. A CPR game describes the case of a group of individuals who may consume or appropriate (portions of) a common resource to the individual's benefit but with an associated social cost. In particular, if aggregate consumption exceeds a certain level then the common resource deteriorates, perhaps completely. Such CPR games are the most frequently used way to model the tragedy of the commons, and they have been extensively studied from both the theoretical and the experimental standpoint;

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see the references in Budescu et al. (1995) (henceforth BRR). The main findings in this body of research include identifying the effects of individual differences and social value orientations (Kuhlman and Marshello, 1975), the positive effect of communication (Orbell et al., 1990), and the positive effect of mechanisms—such as iteration and reciprocity—that are used to enforce credible agreements (Axelrod and Hamilton, 1981).

Two elements of uncertainty are often present in social dilemmas (Messick et al., 1988), the *social* uncertainty about others' actions and the *environmental* uncertainty about the outcomes of those actions. In this paper we explore the effect of environmental uncertainty on the CPR game's outcome. Specifically, we address the following question: Will increased uncertainty about the size of the available common resource lead to more or rather to less consumption at the CPR game's Nash equilibrium?

The literature is rife with robust findings on social uncertainty, but there is less consensus on the impact of environmental uncertainty. There is widespread agreement that social uncertainty leads to defection. In other words, the mechanisms (e.g., communication and formal governance) that reduce social uncertainty are associated with more efficient outcomes (Axelrod and Hamilton, 1981; Dawes et al., 1977; Kerr and Kaufman-Gilliland, 1994; Orbell et al., 1990), which include individuals consuming less of the common resource. Binding agreements between countries—such as international protocols, nonproliferation treaties, and the coordinated use of common resources—can therefore be expected to result in better outcomes for all the parties involved.

However, it is less clear what effects environmental uncertainty has on the equilibrium outcome of the CPR games. Most research indicates that, under reasonable assumptions about the amount of uncertainty associated with the resource, more environmental uncertainty leads to more selfish behavior (Biel and Gärling, 1995; Gärling et al., 1998; Gustafsson et al., 1999; Hine and Gifford, 1996; Messick et al., 1988; Rapoport et al., 1992; Wit and Wilke, 1998). This finding is consistent with the effects of social uncertainty, and it also is reflected in the experimental literature's predominant view that environmental uncertainty encourages defection in both single-shot and repeated settings (Budescu et al., 1992; Rapoport et al., 1993; see also BRR). The policy implication of this result is clear: Individuals will be more cooperative (i.e., will consume less of the resource) if uncertainty about the resource size is reduced. We shall explore this notion by extending previous work after examining the assumptions behind this conclusion. In particular, we show that individuals might decrease their consumption even in the presence of *more* environmental uncertainty under various assumptions in the modeling of uncertainty, of individuals' attitudes toward uncertainty, and of the resource itself.

Rapoport and Suleiman (1992) (henceforth, RS) offer a specific theory about the CPR dilemma of uncertainty inducing defection. These authors propose a game in which individuals decide on their own appropriation levels simultaneously under a common knowledge distribution about the available resource size. This resource size is then realized by a uniformly distributed random variable $\tilde{X}$. If the sum of individual appropriations—that is, the *total consumption*—exceeds the realized value, then the resource is destroyed and all players receive nothing; otherwise, the players each receive amounts equal to their individual requests. We are not aware of any other model of CPR games under uncertainty. In an experimental setting, BRR show that the Nash equilibrium (NE) is a good predictor of a players' behavior in the laboratory version of this game; thus, if the risk associated with the common resource size is high, then increased risk about that size leads to more consumption.

Our model extends the RS/BRR model by examining the robustness of its two key assumptions. First, they assume that the payoff structure is a step function. In other words, if total consumption exceeds the realization of the resource size, then the resource is destroyed and none of the players receive anything. The authors motivate this assumption in terms of biological systems that are sustainable only as long as a predetermined resource threshold is not exceeded. Yet clearly this would be a restrictive assumption in practice. We therefore consider a more general deterioration model—a model (of which RS/BRR's is a special case) that can capture a *gradual* erosion process.

Second, RS and BRR assume not only that the random variable has a specific form (viz., that it is uniform) but also, and more importantly, that the uncertainty associated with resource size can be characterized as 'risk'. Of course, this imposes a specific structure on the individual's attitude toward uncertainty. In the decision sciences literature, *risk* is what characterizes the case where knowledge about the outcomes is not absolute yet the probability of each outcome's occurrence is known. In this sense, risk could be viewed as the lowest degree of uncertainty. To move beyond the connotations of risk, we present a symmetric CPR game that is similar to that of BRR but in which the common resource size (represented by the random variable $\tilde{X}$) is of ambiguous distribution. Ambiguity is a stronger form of uncertainty than risk, and it arises when the possible outcomes are known but the probabilities of those outcomes are not known.

The relevance of accounting for the level of (im)precision in probabilities concerning social dilemmas is both self-evident and widely accepted in the literature. For instance, Biel and Gärling (1995) underscore the importance of distinguishing between types of uncertainty and state that, "in real life resource dilemmas[,] imperfect degree of confidence in the probability of collective or individual negative consequences is likely to be the rule rather than the exception." Several other behavioral and experimental researchers make similar claims—see e.g. the references in Biel and Gärling (1995)—but our paper is among the first to model explicitly the imprecision of probabilities in CPR games. Toward that end, we consider several well-known models of ambiguity—Choquet expected utility (Schmeidler, 1989), the smooth ambiguity model (Klibanoff et al., 2005), and maxmin expected utility (Gilboa and Schmeidler, 1989)—to provide a formal framework for discussing the effect of increased ambiguity on the equilibrium level of consumption.

Our main finding—namely, the possible positive effect of uncertainty on social behavior—is supported by experimental evidence in the literature on group decision making. For example, Gong et al. (2009) find that groups tend to cooperate less