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DOES SCARCITY EXACERBATE THE TRAGEDY OF THE COMMONS? EVIDENCE FROM FISHERS' EXPERIMENTAL RESPONSES

Jorge Higinio Maldonado

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Abstract

Economic Experimental Games (EEGs), focused to analyze dilemmas associated with the use of common pool resources, have shown that individuals make extraction decisions that deviate from the suboptimal Nash equilibrium. However, few studies have analyzed whether these deviations towards the social optimum are affected as the stock of resource changes. Performing EEG with local fishermen, we test the hypothesis that the behavior of participants differs under a situation of abundance versus one of scarcity. Our findings show that under a situation of scarcity, players over-extract a given resource, and thus make decisions above the Nash equilibrium; in doing so, they obtain less profit, mine the others-regarding interest, and exacerbate the tragedy of the commons. This result challenges previous findings from the EEG literature. When individuals face abundance of a given resource, however, they deviate downward from the prediction of individualistic behavior. The phenomenon of private, inefficient over-exploitation is corrected when management strategies are introduced into the game, something that underlines the importance of institutions.

Key words: tragedy of the commons intensified, economic experimental games, resource abundance, resource scarcity, dynamic effects.

JEL classification: D01, D02, D03, O13, O54, Q01, Q22, C93, C72, C73, C23.

¿LA ESCASEZ EXACERBA LA TRAGEDIA DE LOS COMUNES? EVIDENCIA A PARTIR DE JUEGOS EXPERIMENTALES CON PESCADORES

Resumen

Diversos juegos económicos experimentales (JEE), diseñados para analizar el dilema asociado al uso de recursos de uso común, han mostrado que los individuos toman decisiones que se desvían del equilibrio de Nash. Sin embargo, pocos estudios han analizado si estas desviaciones hacia el óptimo social varían cuando el nivel de recurso disponible cambia. Usando JEE con pescadores tradicionales, evaluamos la hipótesis de que el comportamiento de los participantes varía en situaciones de abundancia comparado con situaciones de escasez. Los resultados muestran que bajo condiciones de escasez los jugadores sobre-extraen el recurso, tomando decisiones por encima del equilibrio de Nash; tomando este tipo de decisiones, obtienen menos ganancias, afectan los intereses colectivos y exacerban la tragedia de los comunes. Este resultado desafía hallazgos previos de la literatura de JEE. Sin embargo, cuando los jugadores enfrentan abundancia, se desvían del equilibrio privado esperado de Nash hacia el óptimo social. Cuando se introducen reglas de manejo de los recursos en el juego, el fenómeno de sobre-explotación privada e ineficiente se corrige, lo que resalta la importancia de diferentes instituciones para reducir el dilema.

Palabras clave: tragedia de los comunes, juegos económicos experimentales, abundancia y escasez, efectos dinámicos.

Clasificación JEL: D01, D02, D03, O13, O54, Q01, Q22, C93, C72, C73, C23

1 Introduction

Fisheries have been identified as the typical case of common-pool resources (CPR), one wherein the impossibility of exclusion and the rivalry between users result in their degradation. Gordon (1954) argued that this class of resources, which is considered "free," would not be extracted at the proper time; for fishermen, fish remaining in the sea are valueless, inasmuch as there is no guarantee of finding them in the future if they are left behind today. Hardin (1968) coined the expression "the tragedy of the commons" to describe the overuse and consequent depletion and exhaustion suffered by CPRs as a result of resource users' individualistic behavior. Since then, the "tragedy of the commons" has been used to describe and explain several situations related to CPR and environmental degradation.

Conflicts associated with CPRs have been widely studied in the economic literature, including those related to game theory and behavioral and experimental economics. More specifically, the tragedy of the commons has been formalized using non-cooperative game theory, wherein communication between players is not permitted and all players have complete information about the payoffs associated with their respective decisions (Ostrom, 1990). Predictions derived from non-cooperative game theory establish that under a CPR scenario, players selecting their best individual strategies will not reach a Pareto-optimal outcome, and that individual rational decisions will lead to outcomes that are collectively irrational, a paradox known as the prisoner's dilemma (Ostrom, 1990). In other words, individuals facing CPR dilemmas will make decisions that lead to a suboptimal Nash equilibrium, rather than pursuing strategies that would lead to a social optimum (Cardenas *et al.,* 2003).

Evidence from economic experimental games has challenged this theoretical prediction, showing that individuals deviate from the Nash equilibrium towards social optimum (Ostrom and Walker 1991), and make extraction decisions that balance their own and collective interests (Davis and Holt 1993, Kagel and Roth 1995, Cardenas 2004), even when they are not allowed to communicate with one another (Cardenas, 2000; Cardenas *et al.,* 2000). For instance, in experimental games conducted in rural villages in Colombia, Cardenas *et al.* (2000) calculated individual deviations from Nash strategies when analyzing the balance between self-regarding and others-regarding behavior, and found that when individuals are not subject to any rules, their decisions reflect neither Nash strategies nor socially optimal ones, but rather strategies that fall somewhere between the two. Additionally, when individuals are subjected to internal regulation through communication, their decisions are collectively superior—that is, they are more socially efficient (Cardenas *et al.,* 2000).

Despite the abundant literature regarding these issues, few studies utilizing economic experimental games (EEG) have included the inter-temporal effects associated with CPRs. Moreover, as far as we know, the literature has not analyzed whether deviations from the Nash equilibrium are affected by changes in the resource stock.

In an attempt to contribute to the understanding of the effect of those issues, the objective of this paper is to investigate—through the application of an EEG on real fishermen—the behavior of agents facing CPR dilemmas under two different scenarios, both of which are a consequence of aggregated extraction decisions—resource abundance and resource scarcity.

Our results show that under scarcity and assuming open access, individuals will tend to over-extract a resource, even if this constitutes inefficient behavior; this implies excessive effort and puts greater pressure on ecological systems. In such a case, the tragedy of the commons would be exacerbated.

The paper is organized as follows: in the following part, we discuss the literature related to our research problem; the third part describes the theoretical model supporting our analysis; in the fourth section, we explain the manner in which our economic experimental game was carried out; in the fifth section, we present and discuss the main results; and, finally, in the last section, some policy implications and conclusions are examined.

2 Background

Dynamic effects may exacerbate CPR-related problems, as individuals might not consider the full impact of their current decisions regarding own extraction—likewise, the decisions made by others—on future extraction costs. Herr *et al.* (1997) used laboratory experiments to analyze time-independent and time-dependent externalities of non-renewable commons, and found, not only that the myopic behavior of individuals exacerbates CPR-related problems, but also that even those individuals who take into account the current and future effects of extraction decisions will likely enter into a race for resources if they believe others are acting myopically. Herr *et al.* (1997) state that when inter-temporal effects (e.g., time dependent externalities) are included in a CPR experimental game, the efficiency of resource use will be lower than that obtained in a similar time-independent game. Additionally, they show that, in practice, in a time dependent game, efficiency is even lower than that predicted in theory—this is because of the *temporally* myopic behavior that is only present when time constitutes a factor in the game, inasmuch as it makes the solution process more difficult.

The hypothesis that the tragedy of commons might be intensified has been analyzed by Corners and Sandler (1983) using a static framework. These authors analyze the role of non-zero conjectural variations on the hybrid behavior of fishermen. Corners and Sandler (1983) define hybrid behavior as "the maximizing behavior predicated on conjectures that one exploiter holds with respect to the way in which the other exploiters will respond to his own fishing efforts." They argue that these conjectures are absent in standard CPR models, and that, inasmuch as the presence of a non-zero conjectural variation about what an exploiter thinks contains the effect of his extraction on other extraction efforts, individual responses will deviate negatively or positively from the Nash equilibrium. In order to include conjectures, the authors make the benefits experienced by a firm dependent on, in addition to the firm's own fleet size, the expected response (i.e., the hybrid behavior) regarding the size of the fleet of the entire industry; the latter is taken as a given in the standard model. As a result, if the conjectures are positive—meaning that the firm anticipates that its own increased fishing efforts will likely induce other firms to follow suit—the firm's optimal fleet and the tragedy of the commons will be less than that predicted using the standard solution. In contrast, assuming negative conjectures, the firm's optimal fleet size will be greater than the Nash prediction and, consequently, "the tragedy of the commons will be intensified." In the latter case, the Nash equilibrium represents a less pessimistic prediction about the exploitation of resources (Corners and Sandler, 1983).

Corners and Sandler's paper (1983) leads us to another issue related to CPR games, one that has also been scarcely analyzed—that concerning CPR game responses above the Nash equilibrium. In a CPR experimental game, individuals have to choose their respective levels of extraction from an established range. The Nash equilibrium determines the private efficient level of extraction. Deviations below the Nash equilibrium may reflect collective behavior or other-regarding preferences, as individuals may incorporate a consideration of collective interests in their individual extraction decisions—that is, individuals do not necessarily pursue purely self-interested strategies, as predicted by theory (Cardenas *et al.,* 2002). Conversely, when individuals extract more units than those predicted by the Nash strategy—that is, the deviation is above the Nash equilibrium—the conclusion is that they are being very inefficient, inasmuch as they are making decisions that negatively impact their own private returns.

In general, the literature on experimental games tends to focus more on analyzing individual deviations towards socially efficient outcomes than privately inefficient ones; this is especially true with respect to CPR experimental games. Sometimes, privately inefficient outcomes in CPR games have been seen as rare cases of the experiment that have not been further analyzed. For instance, Cardenas *et al.* (2002) performed experimental games in rural villages in Colombia to explore the role of economic inequality in the provision of local environmental quality; they found that a certain type of player spends more time collecting firewood than what is individually optimal. The authors conclude that these decisions are very inefficient, not only because they are not optimal in the private sense, but also because they are "more environmentally damaging than their Nash strategies" (Cardenas et al., 2002).

Other studies have analyzed the private inefficiency associated with the under-contribution of individuals in public-good games, which, in the mirror case of CPR games, constitutes over-extraction or over-exploitation decisions. In linear public-good games, the maximizing private benefit strategy (i.e., the Nash equilibrium) is to allocate zero units to the public good and all of them to private activity. However, findings from experimental games contradict these predictions, as individuals tend to make important contributions to the public good. This finding is robust for treatments where linear game designs do not allow for negative contributions. To analyze the possibility of under-contribution in public game experiments (i.e., deviations below the Nash equilibrium), some authors have modified the payoff structure to allow for interior solutions, or partial contributions, thus defining payoff functions that are non-linear with respect to both private and public good (Keser, 1996; van Dijk and van Winden, 1997; Isaac and Walker, 1998; Willinger and Ziegelmeyer, 2001). The findings from such studies have been ambiguous. Isaac and Walker (1998) assume a non-linear payoff structure for the public good, and find that over-contribution is not significant for high levels of equilibrium contribution, moreover, that individuals actually tend to under-contribute. Keser (1996) and van Dijk (1997) assume non-linear payoff functions for the private good, and find that over-contribution is significant.

The literature appears to support the idea that the level of the predicted equilibrium contribution plays an important role with respect to contribution decisions, and affects the existence of under-contribution as well as its magnitude. Willinger and Ziegelmeyer (2001) analyze the strength of the social dilemma vis-à-vis contribution behavior; they test four levels of equilibrium (low, medium, high, and very high) and assume a quadratic payoff structure for the private good, where the dominant equilibrium is a unique interior solution. They reduce the strength of the social dilemma by moving the equilibrium contribution to the social optimum, and find that over-contribution is only significant at a low level of equilibrium contribution. This confirms Isaac and Walker's findings (1998), which show that average over-contribution is reduced when the equilibrium level moves towards the Pareto optimum.

Despite arriving at similar findings regarding over-contribution as Willinger and Ziegelmeyer (2001), Isaac and Walker (1998) find that subjects do tend to under-contribute when confronted with high levels of equilibrium contribution. Specifically, Isaac and Walker (1998) evaluate Nash deviations testing four treatments—the first, based on a boundary Nash solution, and the other three, on interior Nash equilibriums at three different levels. Under-contribution is present for all results: in the treatments exhibiting the two highest levels of Nash equilibriums, average investments in the public good are below the Nash prediction, with the findings being more pronounced for the absolute highest equilibrium level. However, under-contribution was not observed for either the treatment based on the corner solution, or the treatment where the interior solution corresponds to the lowest equilibrium level tested. In summary, Isaac and Walker's (1998) show that "within the same experimental group, some individuals follow investment strategies that are highly 'cooperative' while others follow strong 'free riding' strategies, which might explain the under contribution observed in the treatments with highest predicted equilibrium levels." Another important finding from Isaac and Walker (1998) is that upward and downward biases are not the result of pure error.

In fisheries, private inefficiency is known as Malthusian overfishing. This expression was introduced by Pauly (1988, 1990) to describe the over-exploitation of fisheries by poor artisanal fishermen in an effort to maintain their income, something which in turn leads to a spiral of destruction of marine resources, declining extractions, and increasing poverty (Teh and Sumaila, 2006). The concept of Malthusian over-fishing characterizes the over-exploitation of fisheries as consisting of three elements: i) poverty, ii) population growth, and ii) a growing rigidity in income-generating activities (Teh and Sumaila, 2006). Although the degradation of CPR fisheries has its own explanatory characteristics (e.g., non-excludability and rivalry), it might nonetheless be exacerbated where Malthusian over-fishing conditions are present and the respective resource is being depleted and becoming scarce. In developing tropical countries, fishing communities are characterized by low incomes, low levels of education, the utilization of non-appropriate (likewise, non-permitted) fishing methods, and rigidities in labor and capital markets that prevent them from pursuing other income-generating alternatives, thus making the case for Malthusian overfishing as an explanation of fishermen's behavior.

Given the above review of the literature concerning approaches examining social and private inefficiency in the use of public goods and common-pool resources, we focus our contribution on testing the following hypothesis: in dilemmas associated with the use of a CPR, specifically fisheries, individuals facing an abundance of resource tend to cooperate (that is, under-extract), even when no rules are applied; however, cooperation is reduced and individuals might even be privately inefficient when confronted with resource scarcity, as they adopt a "race to the bottom for extraction-profit" strategy. This hypothesis could be understood in different terms: the social dilemma associated with the use of a CPR becomes weaker as the private maximizing-solution level moves towards that of the social (Pareto optimal) solution, whereby a lower level for the Nash equilibrium results from changes in the stock of the resource.

3 Theoretical model

To accomplish our objective, we adopt the dynamic model of profit maximization postulated by Moreno and Maldonado (2008), which not only captures the social dilemma of common pool resources, but also incorporates the inter-temporal effects of aggregated extraction.

The model is based on an individual fisherman benefit function that is non-linear in both the level of private extraction (*x*) and the level of resource stock (*S*). The benefits (and costs) that individuals obtain from the extraction activity are, in turn, divided into two parts: i) the private benefit *f(.),* which depends on the level of extraction (*x*), but the costs of which depend on the availability of the resource (*S*); and ii) the collective benefits or costs *g(.)*,resulting from the extraction decisions made by all of the fishermen using the resource such as affect its availability for other fishermen.[1] This benefit function represents the profits from a common-pool resource (CPR) characterized by non-exclusion and rivalry:

$$\pi_{i,t} = f(x_{i,t}, S_t) + g(\sum_i x_{i,t}) = \alpha x_{i,t} - \frac{\beta x_{i,t}^2}{2S_t} + \gamma \sum_{i=1}^{n} (e - x_{i,t}) , \quad (1)$$

where $\alpha > 0, \beta \geq 0, \gamma \geq 0$ are the parameters, and $\pi_{i,t}$ indicates the benefits fisherman *i* obtains during period *t* from extracting the resource. The private portion of benefits, *f(.),* is assumed to be a quadratic function of extraction (in order to capture the decreasing marginal benefits of extracting), and non-linear for the stock of the resource, with the

[1] It is assumed that $f_x \geq 0, f_{xx} \leq 0, f_S \geq 0, f_{SS} \leq 0, g_x \leq 0, g_{xx} \geq 0$.

assumption of a reserve-dependent cost (i.e., that the cost increases with a reduction in the stock, though not linearly). Function *f(.)* represents a profit function, the revenues of which depend on parameter α (the market price of the resource), and the costs of which depend directly on the extraction and inversely on the stock. The collective portion of the benefit, function *g(.),* is assumed to be linear for the level of extraction, and represents the effect of joint extraction on individual benefits. Parameter *e* represents the maximum amount that each fisherman can extract, and is assumed to be equal for all fishermen. Additionally, aggregated for *n* fishermen—that is, *ne*—it reflects the availability of the resource that is extractable. In this way, the expression $\sum_{i=1}^{n}(e-x_{i,t})$ shows the availability of the resource following its extraction by *n* fishermen. Parameter γ represents the proportion of common-pool resource availability affecting individual benefits (Moreno and Maldonado, 2008).

On the other hand, the resource stock changes according to the evolution equation in expression (2):

$$S_{t+1} = S_t - \sum_{i=1}^{n} x_{i,t} + \theta S_t (1 - \frac{S_t}{K}) \,. \tag{2}$$

The evolution equation states that the amount of the resource in period *t+1* will equal the stock at the beginning of period *t,* minus the extraction of all fishermen during that period, plus the net growth function, which in this case depends on the parameters θ and *K*[2].

The Nash equilibrium of this model is obtained through the maximization of each fisherman's benefits over time, subject to the evolution equation:

$$x^{p}{}_{i,t} = \frac{S_t}{\beta}(\alpha - \gamma - \delta\lambda_{t+1}) \,. \tag{3}$$

This expression represents the Nash equilibrium for the game and shows that the optimum private extraction depends positively on the stock and parameter α (,i.e., the price of the resource), and negatively on the parameter associated with extraction costs

[2] We can assume that the growth function is a logistic function, one where parameter θ represents the implicit growth rate and parameter *K* the carrying capacity of the resource.

(β), the impact of aggregated extraction (γ), and the discounted inter-temporal price of the stock of the resource ($\delta\lambda_{t+1}$).

To obtain the level of extraction maximizing the social welfare, a central planner would aggregate the benefits of all of the individuals, in this case, *n* fishermen, subject to the evolution equation of the stock (Moreno and Maldonado, 2008):

$$\begin{aligned} &\max_{x_{i,t}} \sum_{i=1}^{n} \sum_{t=0}^{T} \delta^t \pi_{i,t} = \sum_{i=1}^{n} \sum_{t=0}^{T} \delta^t \left\{ \alpha x_{i,t} - \frac{\beta x_{i,t}^2}{2S_t} + \gamma ne - \gamma \sum_{i=1}^{n} x_{i,t} \right\} \\ &s.t. \quad S_{t+1} = S_t - \sum_{i=1}^{n} x_{i,t} + \theta S_t (1 - \frac{S_t}{K}) \end{aligned} \quad (4)$$

The Pareto optimum resulting from the first order condition with respect to the extraction would be:

$$x^{soc}{}_{i,t} = \frac{S_t}{\beta}(\alpha - n\gamma - \delta\lambda_{t+1}) . \quad (5)$$

Expression (5) shows that the social level of extraction must be lower than that in expression (3), as the proportion wherein the availability of CPR affects benefits (γ) must be aggregated as the total number of fishermen, *n,* in order to capture the full costs of extraction decisions (Moreno and Maldonado, 2008).

This model, therefore, shows that private extraction decisions should differ from social optimum ones, moreover, that they can range across an ample spectrum depending on the value of the parameters and, particularly, on the level of stock. Lower resource levels should lead to lower levels of extraction as an efficient private decision.

4 Empirical Model

4.1 The model simulation and pay-off structure

In order to construct a pay-off structure that recreates the conflict between the collective and private interests represented in expression (1), Moreno and Maldonado (2008) assign specific values to the parameters in expressions (3) and (5). The parameters used are: α = 100; β = 800; and γ = 20. In addition, they determine the range of plausible extraction equal to [1, 8] and *e* = 8, following previous field experiments conducted by Cardenas (2004).

The dynamic model proposed by Moreno and Maldonado (2008), wherein changes in stock affect individual benefits, yields many Nash equilibriums for each level of stock resulting from each possible aggregated extraction. In order to make the game practical, easy and understandable for real fishermen, the researchers simulated solutions for only two levels of stock: a high level (one of abundance) and a low level (one of scarcity); correspondingly, it was only necessary to construct two payoff tables, one for each stock level. The pay-off tables show the benefits that each individual obtains from different combinations of individual and aggregated extractions (Appendix 1). In these tables, one can observe that as individual *i* increases his or her extraction, the respective payoff increase (at a decreasing rate); on the other hand, as aggregate extraction increases, *i*´s payoff decreases. This simulates the social dilemma between individual and collective interests.

The dynamic setting of the model generates two implications with respect to players' decisions, the first regarding the effect of the aggregated extraction during period *t* on the resource stock at period *t+1*; and the second, regarding the effect of the inter-temporal discount rate on the individual paths of extraction decisions. Therefore, even assuming just two levels of stock, the model still yields several private Nash equilibriums, depending on individuals' respective discount rates. Assuming that a player does not take into account the inter-temporal effects of his or her decisions, the model predicts that, with respect to his or her private extraction decisions, the term $\delta\lambda$ will converge to zero.[3] Consequently, expression (5) becomes:

$$x^{p}{}_{i,t} = \frac{S_t}{\beta}(\alpha - \gamma) \,. \qquad (6)$$

Expression (6) is equivalent to a myopic Nash equilibrium, and we use it to calculate the theoretical benchmarks and payoff tables used in the experiment. Utilizing the parameters mentioned above and assuming an abundant stock—that $S_H = 80$— we arrive at a Nash equilibrium of 8 units; this corresponds to a corner solution, as the range of plausible extraction is [1, 8]. In order to simulate resource scarcity, we assume

[3] This is equivalent to a discount rate (ρ) converging to infinite.

that S_L = 40 and *ceteris paribus*; correspondingly, we obtain a Nash equilibrium of 4 units, which corresponds to an interior solution. Notice that, although under resource scarcity, the Nash equilibrium is four units, individuals might still extract any amount between one and eight units. Correspondingly, for this case, players may deviate from the Nash Equilibrium both downward and upward. Given that cost function is reserve-dependent, the benefits under abundance are higher than those under scarcity; this is true for all levels of extraction. Figure 1 illustrates the average benefits a player may obtain under the two states.

Deviations below the Nash equilibriums imply that individuals either incorporate collective interests into individual decisions, or incorporate with respect to current decisions a consideration of the future consequences of present actions. In the case of low stock, deviations above the Nash equilibrium imply private and social inefficiency, as individuals are making extraction decisions that result in less benefits than those associated with the Nash equilibrium (less extraction); additionally, they are acting more resource-harmful than theory predicts, thus exacerbating the tragedy of the fisheries.

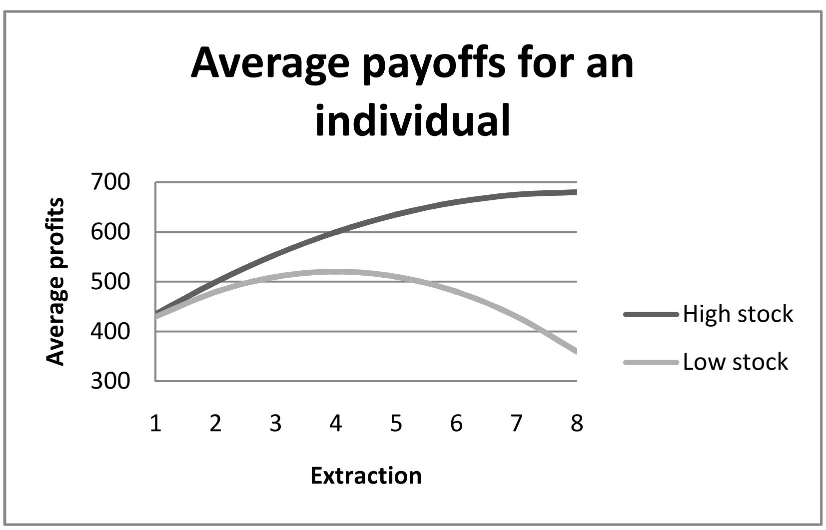

Figure 1. Average payoffs obtained by players under different resource stocks.

Using the same parameters, Moreno and Maldonado (2008) adjust the social optimum equal to one unit[4]; this will also be used in our analyses.

4.2 Experimental design

Based on the theoretical model, we design a CPR economic experimental game consisting of two phases, both of which are made up of ten rounds of decisions. Individuals were organized in groups of five participants, and for every round, each player had to decide in private a level of extraction from one to eight units of resource. A player's extraction decisions generate points, which are convertible into monetary units. On average, US$10 was paid to each person, which is equivalent to a daily wage per person for the region being considered.

The inter-temporal effect of aggregated extraction is captured by the fact that a group's extraction during one period will affect the stock level during the following period. For simplicity's sake, in our design, individuals may only arrive at two stock levels: a high level (one of abundance) and a low level (one of scarcity). The dynamic part of the game was designed as follows: if in round t the aggregated extraction (that is, for a five-person group) exceeds 20 units, during the next round (round $t+1$), each individual will be confronted with resource scarcity; consequently, during round $t+1$, they will use the low availability payoff table to calculate their earnings. Under scarcity, every unit of extraction pays out fewer points, as a low availability of resource implies more effort per unit of catch, which in turn generates, *ceteris paribus,* lower benefits. Conversely, if extraction by the whole group during period t is less than or equal to 20 units, during period $t+1$, the resource will be abundant; less effort is required per unit of catch, and the activity generates higher returns. In that case, the group will use the high availability payoff table in the following round ($t+1$).

During the first phase, players are not subjected to any rules, while during the second phase, they are subjected to three different rules: internal regulation, external

[4] Although our parameters generate a theoretical social optimum of zero units, we follow Cardenas (2004), who argues that it is convenient to eliminate the zero extraction option so as to avoid conflicts when conducting experiments arising because of villagers' strong aversion towards any prohibition against using resources. Additionally, in the NNP-CRSB, fishermen are allowed to extract resources for "self-consumption."

regulation, and a combination of both. An analysis of the management rules was already carried out by Moreno and Maldonado (2008); therefore, this paper will not address issues related to the performance of the rules independently but only jointly, so that we might better concentrate our analysis efforts on the over-extraction hypothesis.

Recall that, according to the profit maximization model and assuming completely myopic behavior, the expected Nash equilibrium for the game under abundance (scarcity) reflects an aggregated extraction of 40 units (20 units), which implies 8 units per player under high stock, and 4 units per player under low stock. The social optimum is a level of aggregated extraction of 5 units (1 unit each).

4.3 Operative procedures

EEGs were performed involving 230 individuals from eight fishing communities located in the vicinity of the National Natural Park Corales del Rosario y San Bernardo (NNP-CRSB) in the Colombian Caribbean.

At every location, participants were organized into groups of five individuals and seated back to back in order to guarantee the anonymity and confidentiality of individual decisions. In addition, a supervisor monitored and controlled the game in order to ensure that rules were understood and adhered to. The supervisor was also in charge of collecting the cards on which the participants wrote their extraction decisions.

Experts on the environmental education of communities explained the game to the fishermen using different visual aids such as drawings, pictures and posters. Three practice rounds were performed before starting the actual game.

5 The analytical methods and results

In order to analyze the behavior of participants in the EEG, likewise, to address the research question, we adopt the following methodological approach, wherein we utilize individual extraction decisions from the first phase of the game (the first 10 rounds, during which no rules were applied):

1. We analyze the frequency of individual extraction decisions and relative deviations from the Nash equilibrium for each resource state, and classify those decisions according to their relationship with the theoretically predicted equilibriums. The differences are then tested statistically. Based on this analysis, we look for decision patterns that help to explain players' behavior, particularly when they decide to extract above the Nash equilibrium. Our categories of individual behavior are drawn from this analysis.
2. As with individual decisions, we search for group decision patterns, especially when these decisions fall above the Nash equilibriums. We then construct categories reflective of group behavior.
3. We examine the relationship between individual behavior and group behavior so as to identify patterns of extraction and the effect that groups can have on individuals.
4. Finally, we run an econometric model that explains differences in extraction decisions and deviations from the Nash equilibrium as, among other variables, a function of socioeconomic factors and resource states.

The procedures and results are presented in the following sections.

5.1 Individual decisions

The first step is to analyze the frequency of extraction decisions for every state. Figure 2 shows that for high stock, we observe with greater frequency extraction decisions of more than five units; 8-unit extraction is the most frequent decision. In the same figure, we observe that when players are confronted with scarcity, extraction distribution is more uniform across the whole range of extraction possibilities. Given that the Nash equilibrium for low stock is interior, at this level, there are extractions that should not be observed (those above four units), as they generate lower benefits than those obtained at the level of extraction that is privately efficient. Extractions above four units under scarcity are inefficient, both privately and socially, since the resource is being overexploited without any marginal benefit (and, in fact, even at a marginal loss). From this figure, it can also be deducted that most of the rounds (60 percent of them) occurred at a low level of stock, while 40 percent of the rounds were played at a high level of stock.

To compare the extraction decisions for the two levels of stock, we calculate the difference between actual extraction and the expected private Nash equilibrium. This measure is what we call the deviation from the Nash equilibrium.

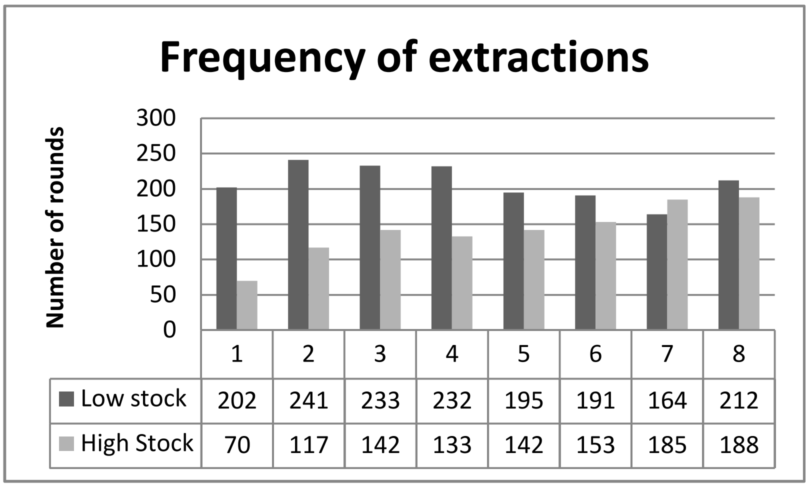

Figure 2. The frequency of different extraction decisions at high and low stocks.

These deviations are classified in groups according to their respective Nash equilibriums. Figure 3 shows that for high stock, 83 percent of decisions were below the equilibrium, implying that they reflect either others-regarding preferences or forward-looking behavior. For low stock, 86 percent of decisions were made outside of the Nash equilibriums, though 46% were privately inefficient decisions. It is worth noticing that when the Nash equilibrium is closer to the social optimum (scarcity), players arrived at the social optimum more frequently (12%).

In summary, when confronted with scarcity, individuals tended to utilize inefficient extraction strategies for almost half of the rounds, thus exacerbating the tragedy of the commons by extracting not only more than the social optimum, but also more than their respective private Nash equilibrium.

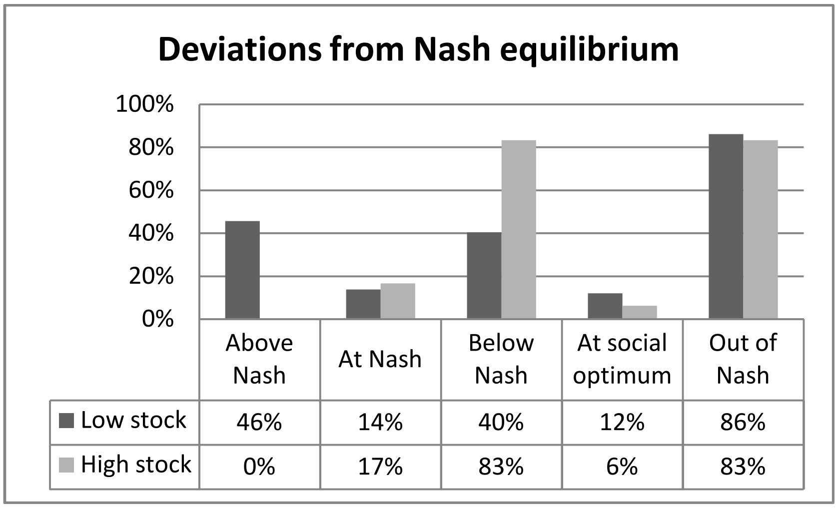

Figure 3. Classification of the deviations from the Nash equilibrium for each resource state.

These findings have several implications:

- When scarcity appears, either collective action or forward-looking strategies are reduced;
- The greater the "distance" between the Nash equilibrium and the social optimum, the less likely it is that players will arrive at the optimum.
- Under low stock, individuals tend to behave inefficiently, both in private and social terms.

Our results coincide with those found in some of the economic literature where it is shown that individuals will likely deviate upward or downward from Nash equilibriums, particularly where public goods are concerned (Isaac and Walker, 1998). Much as with those authors, we have found, for the mirror case of a CPR, that when confronted with a situation of scarcity, players will over-extract the resource—that is, they will make decisions above the Nash equilibrium. In doing so, they obtain less profits, undermine the others-regarding interest, and exacerbate the tragedy of the commons.

To validate these results, we test statistically whether there are significant differences between decisions at the two stock levels, low and high. Table 1 shows statistics for three variables: individual extraction decisions, absolute deviations from the

Nash equilibrium, and relative deviations from the Nash equilibrium.[5] The analysis of statistical differences is only useful for the latter variable. Two tests on differences are used: a t-test on averages and a Mann-Whitney test.

Table 1. Statistical analysis of the differences in individual decisions at both levels of stock.

Variable	**Individual extraction**	**Individual deviation from Nash**	**Individual relative deviation from Nash**
Low stock	4.357	-0.357	-8.9%
High stock	5.035	2.965	37.1%
Difference			-46.0%***
Mann Whitney z			-20.98***

* significant at 10% ** significant at 5% *** significant at 1%

Differences between relative deviations from the Nash equilibrium are highly statistically significant, showing that decisions under high stock differ from those under low stock.

Additionally, we think that over-extracting behavior under scarcity may be associated with certain particular individuals, and not with the whole set of players. To test this hypothesis, we divide the sample according to the number of rounds in which every participant played above the Nash equilibrium.

Based on this, participants were categorized depending on the average number of rounds in which they decided to play above the Nash equilibrium: some never played above it, others played less than half of the time above it, and still others played more than half of the time above it. The results, presented in Figure 4, show that one quarter of participants never played above the Nash equilibrium; almost another quarter played above the Nash equilibrium more than half of the rounds; and about half of the participants played less than half of the time above the Nash equilibrium (though did so at least once).

[5] The relative deviation from Nash for every individual is calculated as *[Nash eq. – extraction] / Nash eq*.

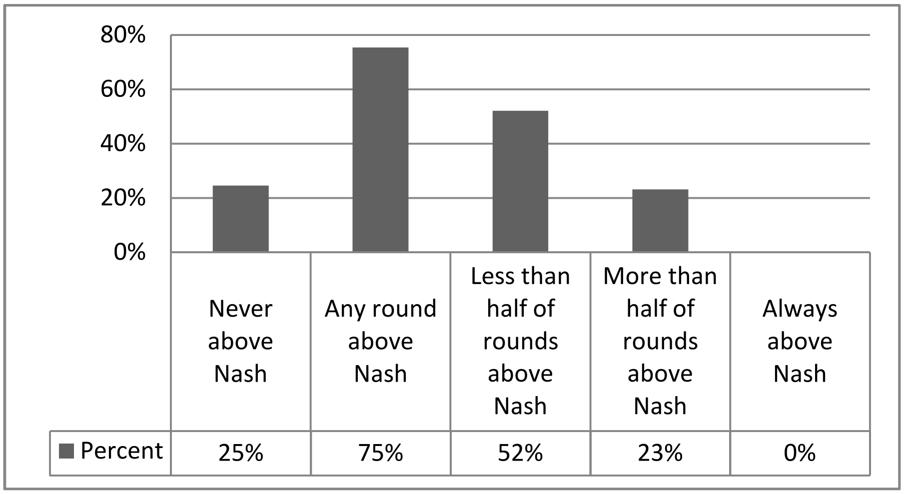

Figure 4 Categories of players according to their behavior with respect to the Nash equilibrium.

These findings imply that, individually, some players may have pro-social attitudes ("good guys" in social and environmental terms), some have individualistic attitudes, and some have exacerbating attitudes, even if suffering economic losses as a consequence of acting them out ("bad guys" in social and environmental terms).

5.2 Group decisions

To analyze group behavior, we perform the same analysis for groups as we did for individuals.

We found that while some groups acted cooperatively and sustainably—that is, they never extracted above the Nash equilibrium (23%)—others played most of the rounds above the Nash equilibrium (38%). These findings are presented in Figure 5.

Comparing individual and group behavior, it might be deduced that "bad guys" were more widely dispersed than "good guys" among the groups, thus generating inefficient behavior in a larger share of groups (38%). "Good guys," conversely, appear to have been more concentrated, within "good groups" (23%).

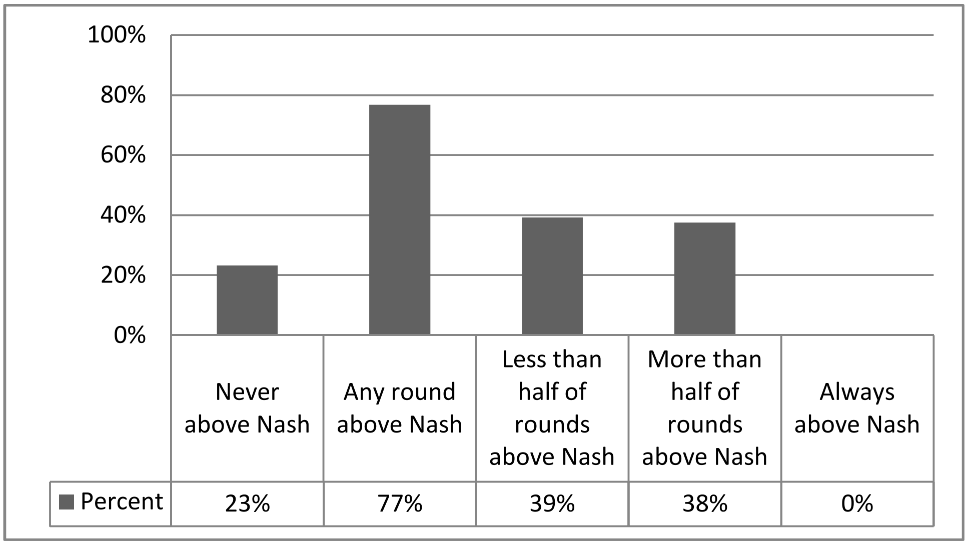

Figure 5. Categories of groups according to their behavior with respect to the Nash equilibrium.

Similar to individual results, some groups consistently behaved cooperatively by never extracting above the Nash equilibrium ("good" groups in social and environmental terms); some groups exhibited behavior closer to the Nash equilibrium; and some groups repeatedly extracted in an inefficient way ("bad" groups in social and environmental terms).

Inasmuch as there are individuals that behave inefficiently throughout the game and individuals that consistently exhibit pro-social behavior throughout the game, likewise, groups that show similar patterns, the question becomes whether or not "good guys" always belong to "good" groups. In Figure 6, we observe that good players coincide with good groups for a high proportion of the rounds associated with good groups (77%); similarly, bad guys coincide with bad groups for more than 60 percent of the rounds associated with bad groups.

In those groups that over-extracted the resource, 25 percent of the players were "good guys," in the sense that they made an effort to not over-extract the resource. They consistently tried to reduce the group's extraction, but their effort was canceled out by the inefficient behavior of the rest of the group. As a result, most of the time, they were confronted with scarcity, and consequently, their profits were reduced. Conversely, seven percent of the players belonging to "good" groups, consistently over-extracted and derived profit from it; at the same time, the pro-social behavior of their respective groups kept them in abundance, as a consequence of which they ended up making greater profits. In essence, they are free riders that took advantage of high levels of extraction while their groups, through their overall efficient and pro-social decisions, maintained high resource availability.

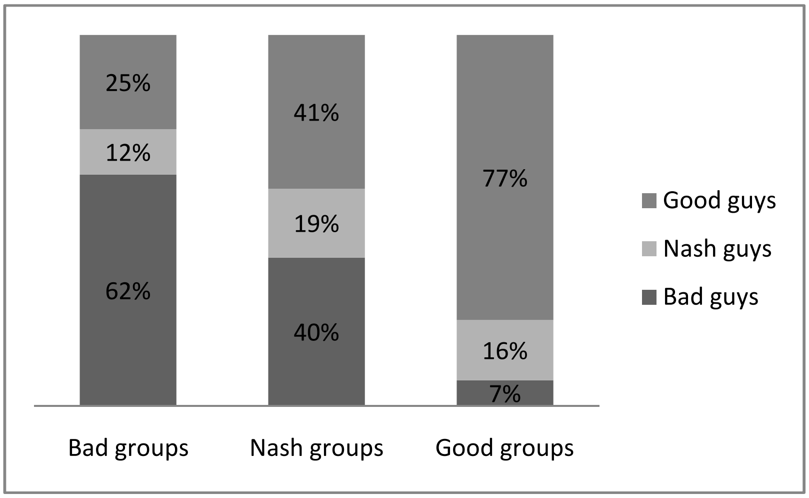

Figure 6. The relationship between individual and group decisions with respect to the Nash equilibrium.

These free riders may erode their respective group's pro-social behavior and induce good players to start playing inefficiently. On the other hand, good players in bad groups may send signals to the other players through their behavior that they should reduce their over-extraction. To analyze if such cases were observed, we calculated the average extraction decisions of players categorized according to their extraction patterns and the type of group to which they belonged: pro-social or good guys playing in either good or bad groups, and inefficient or bad guys playing in either good or bad groups. The results are presented in Figure 7. It can be observed, in fact, that bad guys maintained inefficient behavior throughout the game, as on average, they extracted above four units, while the pro-social behavior of good guys was evident in an average extraction consistently lower than four units. However, the behavior of the bad guys was influenced by their respective group's behavior, as their average extraction was lower when belonging to a good group (the difference being statistically significant). On the other hand, the behavior of the good guys was also affected by the type of group to which they belonged; when belonging to a bad group, good guys were forced to reduce their extraction even further than what would have been the case if belonging to a good group—that is, the good guys sacrificed their own benefits in order to keep their respective group pro-social. These results show that groups matter.

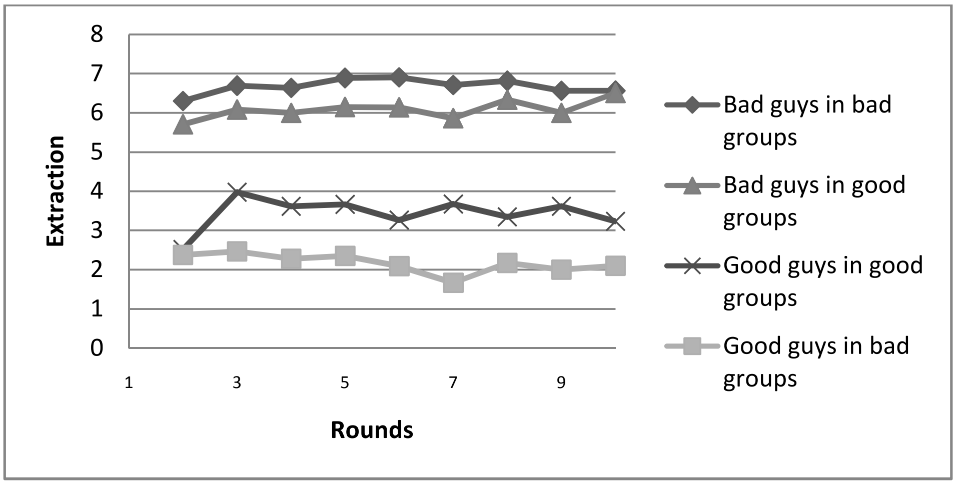

Figure 7. The average extraction of individuals according to Nash categories.

The second part of the game involved the introduction of rules aimed at increasing collective action and behavior efficiency. These rules included external regulation, internal regulation (communication), and a non-coercive combination of the two (co-management). The findings show that the rules were effective in reducing extraction (Moreno and Maldonado, 2008). However, under scarcity, deviations below the Nash equilibrium continued to be statistically lower than those corresponding to a situation of abundance.

5.3 Econometric analysis

The results concerning our hypothesis that, under scarcity, individuals exacerbate the tragedy of the commons by making decisions above the private Nash equilibrium are formalized through a parametric analysis.

In the proposed econometric model, the explained variable is the relative deviation from the Nash equilibrium[6] ($RDN_{i,t}$), which depends on: i) the conditions of the game (i.e., the current-round´s stock level (S_t), the group's extraction ($\Sigma x_{t-1}=X_{-i,t-1}$) and individual's extraction ($x_{i,t-1}$) during the previous round); ii) the type of group to which a participant belongs (a good group ($GG_{i,t}$), a Nash group or a bad group ($BG_{i,t}$)); iii) certain demographic and socioeconomic conditions (age, education and income); and iv) perceptions about the protected area. The econometric model can be written as:

$$RDN_{i.t} = \beta_0 + \beta_1 S_t + \beta_2 x_{i,t-1} + \beta_3 X_{-i,t-1} + \beta_4 BG_{i,t} + \beta_5 GG_{i,t} + \beta_6 AGE_i + \beta_7 EDU_i + \beta_8 INC_i + \beta_9 INFO_i + \beta_{10} WTC_i + \varepsilon_{i,t}$$

Demographic, socioeconomic and perception-related variables were collected through a survey of the players after the game had concluded. Given that the decisions of each individual over ten rounds are not independent, we adopt a panel data structure so that any error associated with the rounds within a particular player can be separated from errors related to between-individuals variations. As the model uses lagged variables, information about the first round is dropped. The results for the estimated econometric model are presented in Table 2.

The relationship between dependent and independent variables should be interpreted as follows: positive coefficients imply that any increase in the independent variable will result in a greater pro-social attitude by the player. Conversely, negative coefficients mean that an increase in the independent variable will result in more self-centered or even privately inefficient behavior.

The findings show that the resource stock during a current round has a positive relationship with the relative deviation from the Nash equilibrium during that period. This implies that if a current round exhibits abundance, for period t, on average, extraction decisions will exhibit greater relative deviation from the Nash equilibrium towards the social optimum. On the other hand, every additional unit of individual extraction during the previous round (t-1) will result in an upward deviation during the current round,

[6] Recall that the relative deviation from the Nash equilibrium for every individual is calculated as *[Nash eq. – extraction] / Nash eq*.

period t. This confirms that "bad guys" tend to remain "bad" throughout the game. Conversely, greater extraction by some group members during a previous round encourages individuals during the current round to behave cooperatively; they thus deviate downward from the Nash equilibrium.

Table 2. Panel regression explaining individual relative deviations from the Nash equilibrium.

Dependent variable: relative deviation from Nash			**Coefficient**	**Std. Err.**
Resource stock current round (1 = high, 0 = low)			0.059*	0.032
Own extraction previous round (1-8 units)			-0.056***	0.005
Other members' extraction previous round (4-32 units)			0.005*	0.003
Belonging to a bad group (1 = bad group, 0 = no bad group)			-0.294***	0.042
Belonging to a good group (1 = good group, 0 = no good group)			0.202***	0.043
Age (years)			0.001*	0.001
Education (years of education)			0.018***	0.003
Per capita income (monthly minimum wages)			-0.168***	0.042
Has received info about protected area (1 = yes, 0 = no)			0.068***	0.024
Willingness to collaborate with park management (1=yes, 0=no)			0.074***	0.022
Constant			-0.086 [ns]	0.096
Observations	2,164	Groups	196	
R-sq within groups			0.142	
R-sq between groups			0.765	
R-sq overall			0.379	
Wald Chi-sq(k)			1,313	

* significant at 10% ** significant at 5% *** significant at 1% [ns] not significant

The categorical variables used to capture group effects show significant coefficients and the expected signs: being in a 'good' group is associated with deviations towards the social optimum, while being in a bad group is associated with deviations towards inefficient behavior. These results confirm the conclusion that the type of group matters and that there is a group effect on deviation.

With respect to demographic variables, we observe that the greater the age and level of education, the greater the deviation away from the Nash equilibrium; older and more educated players tended to move towards the social optimum.

Per capita income shows a negative relationship with respect to the degree of deviation away from the Nash equilibrium, implying that less poor individuals extract closer to the Nash equilibrium or above it. This result challenges the usual assumption that poorer people impact more heavily on natural resources. However, the surveyed communities exhibited a small amount of variance with respect to the income variable.

Finally, individuals who received some information (through training, workshops, etc.) about the importance of the protected area (*INFO*), or who indicated a willingness to collaborate with environmental authorities in the management of the park (*WTC*), deviated downward from the Nash equilibrium to a greater extent—that is, they were more interested in reducing extraction and moving toward social solutions.

6 Conclusions

The objective of this paper was to investigate whether deviations downward from the Nash equilibrium in CPR economic experimental games—which have been explained in the literature as a result of collective behavior or others-regarding preferences—are affected by resource availability. To do that, we developed an EEG for a CPR with real fishing communities at a national park in the Colombian Caribbean, and simulated two stock levels (scarcity and abundance), using a benefit function—quadratic with respect to private extractions and non-linear with respect to the stock level—which in turn generated two Nash equilibriums.

Although other EEGs performed with local communities have demonstrated that individuals deviate downward from the Nash equilibrium—deviating away from the myopic and individualistic behavior predicted by non-cooperative game theory and Hardin (1968)—our findings show that under scarcity, individuals reduce their pro-social behavior, and might even be privately inefficient, and thus deviate upward from the

Nash equilibrium. In terms of resource sustainability, such inefficient behavior implies that individuals not only obtain less profit and undermine others-regarding preferences, they also exacerbate the tragedy of the commons.

Much as with previous studies (Isaac and Walker, 1998; and Willinger and Ziegelmeyer, 2001), we find that the "distance" from the theoretical social optimum to the private Nash equilibrium is important for defining the chances of arriving at the social optimum. Under scarcity, the private Nash equilibrium is closer to the social optimum; therefore, we are more likely to observe individuals making decisions that correspond with that optimum.

As with Isaac and Walker (1998), we find that there are individuals that act as free riders vis-à-vis their fellow group members; they extract at the Nash equilibrium or over it, even while the latter consistently remain "highly cooperative," and try to deviate downward from the Nash equilibrium. Seven percent of the players associated with "good" groups consistently over-extracted during the game, even while their respective groups maintained high stock availability for them, thus allowing them to obtain greater profits. They are effectively free riders of the "good" groups, groups that maintained high resource availability through their efficient and pro-social decisions.

Similarly to Herr *et al.* (1997) who, analyzed the effect of time on externalities associated with the extraction of non-renewable resources, we find that the myopic behavior of individuals not only exacerbates the CPR problem, but also affects the behavior of non-myopic individuals, leading all group members to a race for the resource; group behavior matters and individual extraction is positively related with the type of group to which said individual belongs—this reflects reciprocity attitudes: "*they extract more in previous period, therefore I will extract more at current period.*"

The results from our parametric analysis confirm our non-parametric tests with respect to, among other things, our central question: resource abundance induces individuals to deviate further downward from the Nash equilibrium. Socio-economic and demographic variables may also shape the pattern of over-extraction; older and more educated players tend to extract at levels closer to the social optimum.

Analysis of the impact of income challenges the assumption that the poorest exert the most damage on the environment; however, income statistics show that most of the players are below the poverty line, and that the variance between individuals is, in the end, low.

Variables associated with perceptions concerning the importance of the natural park indicate that they play an important role with respect to decisions about the use of the CPR. Players that have received some training about the protected area or that are interested in collaborating with the protected area's management show a greater tendency to deviate downward from Nash equilibrium.

When rules are included in the game, a significant portion of this inefficient behavior vanished. This result highlights the importance of certain institutions in managing resources and controlling the threat of the tragedy the commons, or at the least, minimizing the exacerbation of such conduct.

Our findings provide information that might be useful in the formulation of management strategies for common pool resources; in particular, when CPRs are facing deterioration and local users perceive them as scarce. Individuals might be less interested in cooperating when the resource is becoming depleted; therefore, with respect to resources that are highly threatened, management strategies might best focus on zoning, the establishment of non-take zones and exerting control. However, when a resource is abundant, management strategies might be more effective if local user participation is involved.

This research shows that the collective behavior of individuals facing a CPR dilemma in an EEG is not a rule, and depends on the condition of the stock; under scarcity, individuals deviate from cooperative behavior and may even engage in a race to the bottom.

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Appendix 1. Pay-off tables

Green payoff table for HIGH resource availability and pink payoff table for LOW resource availability.

Green Pay off table or HIGH availability		My own level of extraction (fish catch)							
		1	2	3	4	5	6	7	8
Their level of extraction (rest f the group)	4	795	860	915	960	995	1020	1035	1040
	5	775	840	895	940	975	1000	1015	1020
	6	755	820	875	920	955	980	995	1000
	7	735	800	855	900	935	960	975	980
	8	715	780	835	880	915	940	955	960
	9	695	760	815	860	895	920	935	940
	10	675	740	795	840	875	900	915	920
	11	655	720	775	820	855	880	895	900
	12	635	700	755	800	835	860	875	880
	13	615	680	735	780	815	840	855	860
	14	595	660	715	760	795	820	835	840
	15	575	640	695	740	775	800	815	820
	16	555	620	675	720	755	780	795	800
	17	535	600	655	700	735	760	775	780
	18	515	580	635	680	715	740	755	760
	19	495	560	615	660	695	720	735	740
	20	475	540	595	640	675	700	715	720
	21	455	520	575	620	655	680	695	700
	22	435	500	555	600	635	660	675	680
	23	415	480	535	580	615	640	655	660
	24	395	460	515	560	595	620	635	640
	25	375	440	495	540	575	600	615	620
	26	355	420	475	520	555	580	595	600
	27	335	400	455	500	535	560	575	580
	28	315	380	435	480	515	540	555	560
	29	295	360	415	460	495	520	535	540
	30	275	340	395	440	475	500	515	520
	31	255	320	375	420	455	480	495	500
	32	235	300	355	400	435	460	475	480

Red Pay off table or LOW availability		My own level of extraction (fish catch)							
		1	2	3	4	5	6	7	8
Their level of extraction (rest f the group)	4	790	840	870	880	870	840	790	720
	5	770	820	850	860	850	820	770	700
	6	750	800	830	840	830	800	750	680
	7	730	780	810	820	810	780	730	660
	8	710	760	790	800	790	760	710	640
	9	690	740	770	780	770	740	690	620
	10	670	720	750	760	750	720	670	600
	11	650	700	730	740	730	700	650	580
	12	630	680	710	720	710	680	630	560
	13	610	660	690	700	690	660	610	540
	14	590	640	670	680	670	640	590	520
	15	570	620	650	660	650	620	570	500
	16	550	600	630	640	630	600	550	480
	17	530	580	610	620	610	580	530	460
	18	510	560	590	600	590	560	510	440
	19	490	540	570	580	570	540	490	420
	20	470	520	550	560	550	520	470	400
	21	450	500	530	540	530	500	450	380
	22	430	480	510	520	510	480	430	360
	23	410	460	490	500	490	460	410	340
	24	390	440	470	480	470	440	390	320
	25	370	420	450	460	450	420	370	300
	26	350	400	430	440	430	400	350	280
	27	330	380	410	420	410	380	330	260
	28	310	360	390	400	390	360	310	240
	29	290	340	370	380	370	340	290	220
	30	270	320	350	360	350	320	270	200
	31	250	300	330	340	330	300	250	180
	32	230	280	310	320	310	280	230	160